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Three species of Scapania from western North America[1]

ALEXANDER W. EVANS

(WITH EIGHT TEXT FIGURES)

In Buch's recent treatise on the Scapaniaceae of northern Europe and Siberia (3), he divides the genus *Scapania* into three subgenera. The second of these, EUSCAPANIA, which includes all but one of the North American species, he subdivides into thirteen sections, all of which are represented in our flora. Some of these are equivalent to the 'groups' into which Müller (13, 14) divided the genus, but others represent new conceptions. Müller emphasized the difficulty of assigning distinctive characters to his groups and made no attempt to do so in several instances. Buch, however, has based his sections on definite combinations of characters, and his work therefore represents an important advance in the taxonomic study of this difficult genus.

In the present paper three species of western North America are discussed from the standpoint of Buch's ideas, although these particular species do not occur in the area covered by his investigations. The species studied are *S. Bolanderi*, *S. americana*, and a species proposed as new under the name *S. granulifera*. Although these species have certain important features in common, they belong to three different sections, according to Buch's classification.

I. SCAPANIA BOLANDERI

The present species is one of the most characteristic hepatics of the Pacific Coast region. It usually grows on decayed logs or stumps or on the bark of living trees but is sometimes found on rocks or shaded soil. Its known range extends from southern Alaska to northern California, and it occurs also in Japan. The published records from eastern North America, however, are probably all based on incorrect determinations. The synonymy of the species is as follows:

SCAPANIA BOLANDERI Aust. Proc. Acad. Nat. Sci. Philadelphia **1869**: 218.

Scapania californica Gottsche in Bolander, California Med. Gaz. **1870**: 184 (name only).

Scapania albescens Steph. Bot. Jahrb. **8**: 96. *pl. 3, f. 9.* 1886.

[1] Contribution from the Osborn Botanical Laboratory.

[THE BULLETIN FOR JANUARY (**57**: 1–86) WAS ISSUED 14 MAY 1930.]

Scapania caudata Tayl. in Pearson, List Canadian Hep. 13. 1890 (as synonym); Stephani, Sp. Hep. **4**: 136. 1910.

Aside from Austin's original description, which is unusually clear, *S. Bolanderi* has been described by Howe (10, p. 147), by Müller (13, p. 184), by Clark & Frye (5, p. 143), and by Sanborn (16, p. 76). Illustrations have been published by Pearson (15, *pl. 7*), by Howe (10, *pl. 106, 107*) by Müller (13, *pl. 21*), and by Clark & Frye (5, six figures after Howe), in addition to Stephani's figure of *S. albescens*. Numerous stations for the species have been reported in the literature, especially in papers by Clark & Frye (5), Haynes (9), Howe (10), Macoun (11), Müller (13), Pearson (15), Sanborn (16), and the writer (6, 7, 8). The specimens listed below, however, are presumably cited for the first time:

ALASKA: Gold Creek, near Juneau, 1891, *G. E. Cooley* (N. Y.)[2]; Sitka, 1891, *G. E. Cooley* (N. Y.); near Sitka, 1891, *W. G. Wright* (N. Y.); Sitka, 1894, U. S. Fish Commission; Catala, 1904, *G. C. Britton 27, 31*; Douglas, 1908, *L. Clark 1, 8*; Hilda Creek Douglas Island, 1909, *L. Clark*; Excursion Inlet, 1921, *W. S. Cooper 58*. Miss Cooley's specimens have been reported (Bull. Torrey Club **19**: 247. 1892) as *S. nemorosa*.

BRITISH COLUMBIA: Glacier, 1902, *S. A. Skinner 16*; New Westminster, 1904, *A. J. Hill*; Departure Bay, 1908, *J. Macoun 3, 9*; Goldstream, 1908, *J. Macoun 20*; Victoria and vicinity, 1908, *J. Macoun 33, 35–42*; Ucluelet, 1909, *J. Macoun 10, 11, 12, 13, 74*, specimens from this locality distributed by Miss Haynes, Amer. Hep. *69;* Skidegate, Queen Charlotte Islands, 1910, *W. Spreadborough*; Bella Coola Valley, 1911, *A. Brinkman 13, 154;* Shell Island, Beaver Bay, Queen Charlotte Sound, 1913, *T. C. Frye 1138;* Lewis Island, northeast of Porcher Island, 1913, *T. C. Frye 1152, 1153, 1154.*

WASHINGTON: near Montesano, 1898, *A. A. & E. G. Heller 4322* (N. Y.); Pacific Beach, 1911, *A. S. Foster 1506, 1508*; Montesano, 1918, *J. M. Grant 2026, 2038, 2036*; Friday Harbor, 1922, *E. R. Walker 4*; same locality, no date, *L. Clark 1*; Cherryvalley, King County, no date, *J. V. Getty*; Lakota, 1924, *L. Clark 111.*

OREGON: Three Rivers, Coast Mountains, 1901, *J. E. Kirkwood 78* (N. Y.); Silverton, 1910, *A. S. Foster 1237*; Portland, 1921, *C. C. Potter 11, 13, 25*; Newport, 1921, *A. M. Dougherty D 2*; Miner Creek, Coos County, no date, *E. I. Sanborn*, cited (16, p. 79) as *S. nemorosa*; vicinity of Government Camp, Mt. Hood Highway, 1929, *J. Carson.*

CALIFORNIA: near Oricks, Humboldt County, 1923, *A. Eastwood 5.*

JAPAN: near Takachi, province of Yezo, 1905, *Faurie* (distributed in Hep. Japon *1846* as *S. caudata*); near Morioka, on Mt. Hayachine, province of Iwate, 1894, *Faurie* (distributed in Hep. Japon. *14413* as *S. Bolanderi*).

Austin compared *S. Bolanderi* with the common and widely distributed *S. nemorosa* (L.) Dumort., and Müller in his monograph on *Scapania* (13, p. 184) places it in his group 'NEMOROSA' which is of course typified by

[2] Specimens marked 'N. Y.' are in the herbarium of the New York Botanical Garden; the other specimens listed are in the herbarium of Yale University.

S. nemorosa. He points out, however, its very close relationship to *S. gracilis* (Lindb.) Kaal., and Buch expresses the opinion (3², p. 110, footnote) that it represents *S. gracilis* vicariously on the Pacific Coast. Although Müller includes *S. gracilis* also in his group NEMOROSA, Buch makes it the type of his new section GRACILIDAE, which he separates rather widely from his section NEMOROSAE.

Among the characters which he assigns to the GRACILIDAE the following are perhaps the most distinctive: a stem-cortex composed of from two to four layers of cells with strongly thickened walls; multicellular foliar teeth, the terminal cell being only slightly longer than broad; the line of attachment of the dorsal lobe almost transverse near the keel, then slightly curved backward but not extending beyond the level of the keel; the line of attachment of the ventral lobe gently curved toward the stem-apex near the keel, then curved backward but extending scarcely farther than that of the dorsal lobe; thick keels composed of several layers of cells; a group of teeth or a toothed lobe of some sort at the base of the dorsal lobe; a minutely papillose cuticle; a perianth-mouth with toothed lobes; and two-celled, green gemmae.

In the following account of *S. Bolanderi* attention is called to the more important features of the species, and the attempt is made to bring out specific characters of the type emphasized by Buch in his descriptions. It will be shown that most, if not all, of these characters will justify the inclusion of the species in the GRACILIDAE.

The plants grow in depressed mats, sometimes pure and sometimes mixed with other bryophytes, and these mats are often of considerable extent. The color varies from green or yellowish green to olive brown or olive green but apparently never shows purplish or reddish shades. The rigid stems are simple or sparingly branched and often show one or two subfloral innovations, especially in cases where the archegonia have remained unfertilized.

The stems are more deeply pigmented than the leaves and often appear dark brown or almost black. In cross-section (fig. 1, *A*) the well-marked cortex stands in sharp contrast to the pale or almost colorless medulla, although the transition from one to the other is fairly gradual. The cortical cells are mostly in three to five layers, and their strongly thickened walls are deeply pigmented with brown. In most cases the boundaries of the cells are marked by darker lines or narrow bands, which fade gradually into the paler layers lining the cavities. The deposits of thickening are usually so pronounced that the cavities, especially in the outer layers, are reduced to narrow slits, parallel with the circumference of the section.

The walls of the medullary cells are fairly thin except at the angles, where minute triangular thickenings are usually apparent; the walls are sometimes hyaline and sometimes show a very pale brownish pigmentation.

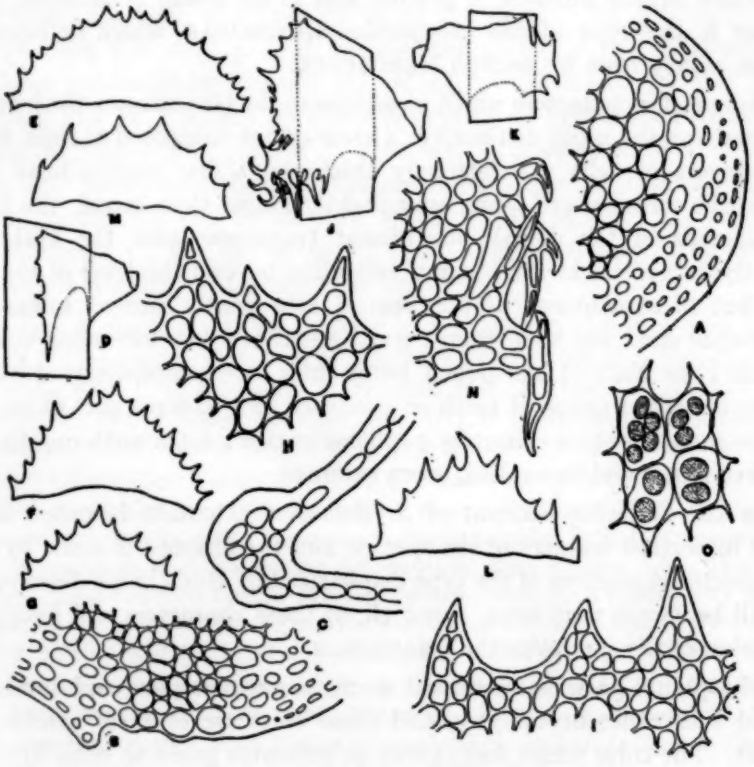

Figure 1. SCAPANIA BOLANDERI Austin

A. Cross-section of stem, lateral portion, ×225. B. Cross-section of stem, ventral portion, ×225. C. Cross-section of keel of leaf, ×225. D. Base of ventral lobe, ×40. E-G. Apices of ventral lobes, ×40. H, I. Teeth from near apex of ventral lobe, ×225. J, K. Bases of dorsal lobes, ×40. L, M. Apices of dorsal lobes, ×40. N. Teeth from basal portion of dorsal lobe, ×225. O. Cells from median region of ventral lobe, ×300. A-C, G, I-K, and N were drawn from a specimen collected by Trelease and Saunders at Orca, Alaska (No. 1491); D-F, H, L, and M, from a specimen collected by Howe at the North Fork of the Little River, Mendocino County, California (No. 648); and O, from a specimen collected by J. Carson near Mt. Hood, Oregon.

Although the medullary cells appear much larger than the cortical cells, owing to their larger cavities, the actual difference in size is not very great. In the section figured the medullary cells averaged about 16 microns in diameter and the cortical cells about 12 microns.

On the ventral side of the stem the cortex is interrupted by a narrow

longitudinal band developed from the ventral segments cut off from the apical cell. In the section drawn (fig. 1, *B*) this band is four cells wide at the surface, and the base of a ventral lobe is shown at the left. The band shows little or no pigmentation and represents an extension of the medulla to the surface. In some cases the superficial cells grow out into rhizoids, but in cases where no rhizoids are present the walls of these cells, as in the section figured, may be more or less thickened.

The leaves are approximate or more or less imbricate. The keel is short, measuring about one-fifth the length of the ventral lobe, and meets the stem at an angle of about 60 degrees; it is sometimes nearly straight and sometimes slightly arched, the angle formed with the stem often increasing to 90 degrees. According to most of the published descriptions the keel is narrowly winged, but this condition is by no means frequent. The cross-section of a keel (fig. 1, *C*) shows a definite enlargement where the lobes meet, this enlargement being about four cells thick from top to bottom. Sometimes two cells are present at the curvature and sometimes only one. In the latter case the keel might appear very narrowly winged in an intact leaf, but the projection would hardly be definite enough to constitute a true wing. In the rather rare cases where a true wing is developed the margin may be entire or bear one or more sharp teeth. The cells of the keel are separated from one another by fairly thin walls, but the outer and inner boundary walls are strongly thickened and form continuous membranes with the thick upper and lower walls of the lobes.

The ventral lobes spread widely and are strongly convex; they are mostly 1.5–2 mm. in length by 0.75–1 mm. in width and vary in form from oblong-ovate to oblong-obovate, the lateral margins being approximately parallel. The line of attachment to the stem (fig. 1, *D*) is distinctly curved toward the stem-apex and then arches abruptly toward the base in an almost straight direction, sometimes ending at the level of keel and sometimes extending considerably beyond. The apices of the lobes are usually broad and rounded (fig. 1, *E*) and are only exceptionally more pointed (fig. 1, *F*, *G*). The margin (except in the vicinity of the keel) is coarsely, sharply, and irregularly dentate. A few of the teeth are unicellular (fig. 1, *H*, middle tooth), but the majority are multicellular (fig. 1, *H*, *I*) and sometimes attain a length of four or five cells and a width of three or four cells at the base. They are in the form of relatively broad triangles and are tipped by a single cell or by two superimposed cells, the terminal cells being only a little longer than broad. The tooth at the tip of a lobe is sometimes a trifle larger than its neighbors but is often indistinguishable except by its position.

The dorsal lobes are considerably shorter than the ventral and spread

much less widely. They are mostly 0.9–1.2 mm. long by 0.75–1 mm. in width, and their form is broadly ovate. In most cases they are definitely convex and more or less appressed to the stem. The line of attachment (fig. 1, *J*, *K*) curves slightly toward the stem-apex and then arches backward but scarcely extends beyond the level of the keel. The marginal teeth (fig. 1, *L*, *M*) are similar to those of the ventral lobe but are usually larger and fewer. At the free base the ciliate portion, originally noted by Austin and emphasized by Howe, is a conspicuous feature, although careful separation of the imbricate lobes is often essential for its demonstration. It represents one of the most distinctive features of *S. Bolanderi*, and yet few of the published figures, with the exception of Howe's (10, *pl. 106, f. 4, 6*), show it at all distinctly. Sometimes, as shown in figure 1, *K*, the ciliate portion is relatively simple, but when well developed it forms a more or less distinct auricle or lobe (fig. 1, *J*). The cilia are often branched, densely crowded and interwoven, some of them frequently pointing backward. In certain instances (fig. 1, *N*) they approximate a T-form and give off branches in opposite directions.

It is clear that the ciliate portions of the dorsal lobes must enhance to a considerable extent the capillary properties of the imbricate leaves. The capillarity of the shoots is made still more effective by the paraphyllia or paraphyses, which Howe first described and figured (10, *pl. 107, f. 13*) in connection with the axils of the antheridial bracts. They are not, however, confined to the antheridial bracts but are sometimes found in the axils of the perichaetial bracts or even in those of ordinary vegetative leaves. These paraphyllia are in the form of simple or sparingly branched filaments or narrow leaf-like organs and are sometimes produced in considerable abundance.

In the median and basal portions of the lobes the leaf-cells are characterized by large trigones, often with bulging sides, a condition clearly shown in the figures published by Howe (10, *pl. 107, f. 15*) and by Müller (13, *pl. 21, f. 5*). Along the margins, however, the trigones are more or less coalescent, and one or two rows of marginal cells often appear as if their walls were uniformly thickened (fig. 1, *H*, *I*). The upper and lower walls are likewise strongly thickened, as shown in figure 1, *C*, and present the appearance of continuous membranes, forming a hyaline band where they meet at the margins. The thick-walled conditions described are distinctive of the modifications *pachyderma* and *mesoderma*, as defined by Buch (3^2, p. 7), and indicate that the species prefers more or less xerophytic habitats. The leaf-cells average about 13 microns at the margin, 22×17 microns in the middle and 27×18 microns at the base; and the cuticle is minutely and often indistinctly verruculose or striate-verruculose.

The importance of the oil bodies in the leaf-cells, from a taxonomic standpoint, has recently been emphasized by Buch (3[1], p. 19). Unfortunately these bodies are rarely to be seen in herbarium material, so that fresh material is usually essential for their study. In the case of *S. Bolanderi* living plants have been supplied through the kindness of Miss Ethel I. Sanborn, of the University of Oregon. The cells drawn from this material (fig. 1, *O*) show that the oil bodies are of large size in the median portion

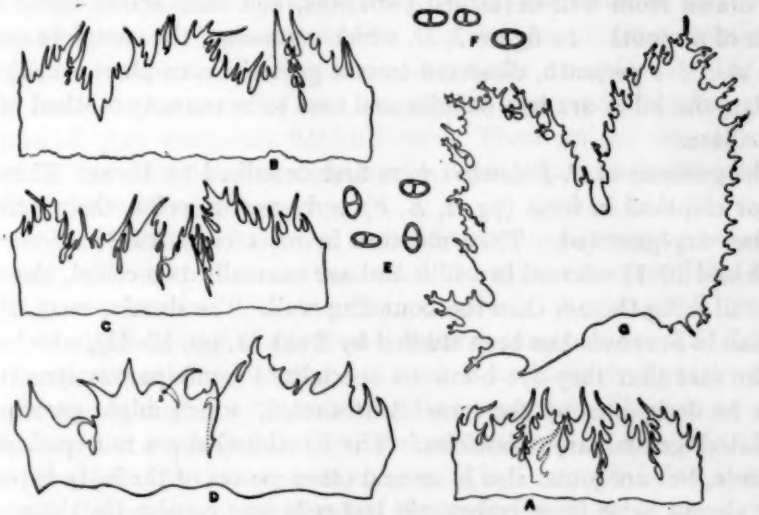

Figure 2. SCAPANIA BOLANDERI Austin

A-D. Lobes and teeth from mouths of perianths, ×40 E, F. Gemmae, ×225. G. Gemmiparous leaf from median portion of gemmiparous region, ×40. A was drawn from a specimen collected by Howe at the North Fork of the Little River, Mendocino County, California; B, from a specimen collected by Frye at Port San Antonio, Alaska (No. 600); C, from a specimen collected by Trelease and Saunders at Orca, Alaska (No. 1491); D and E, from a specimen collected by Brinkman in Bella Coola Valley, British Columbia (No. 137); and F and G, from a specimen collected by Frye at Lake Bay, Alaska (No. 207).

of the ventral lobe and that they vary in number from two to five in each cell. In the basal portion of the lobe they are smaller and more numerous, as many as ten being sometimes present. The bodies are circular to elliptical in outline and show a finely granular structure and a grayish color when seen in transmitted light. The oil bodies of *S. gracilis*, as figured by Buch (3[2], *f. 23*[9]), are very similar but are described as brownish.

The mouth of the perianth often yields differential characters in the genus *Scapania*. In *S. Bolanderi*, as shown by Howe (10, *pl. 107, f. 14*), the perianth is normally coarsely lobed at the mouth, the lobes being

separated by narrow sinuses and bearing a series of cilia on each side. The lobes themselves run out into slender points, which are usually longer than any of the lateral cilia. This condition is shown in figure 2, *A*, where the two lobes at the left are somewhat smaller and less complex than the others. Figure 2, *B* and *C*, will give some idea of the variation in size to which the lobes are subject and show that the larger lobes may bear secondary lobes on their sides instead of simple cilia. These three figures were drawn from well-developed perianths, and each shows about one-fourth of a mouth. In figure 2, *D*, which represents the complete mouth of an abortive perianth, dissected from a gemmiparous plant and spread out flat, the lobes are less definite and tend to be coarsely toothed rather than ciliate.

The gemmae of *S. Bolanderi* were first described by Howe. They are oval or elliptical in form (fig. 2, *E*, *F*) and green in color, their walls remaining unpigmented. They measure in most cases 20–26 microns in length and 10–12 microns in width and are normally two-celled, the dividing wall being thinner than the bounding wall. The development of the gemmae in *Scapania* has been studied by Buch (2, pp. 12–23), who brings out the fact that they are borne on specialized gemmiparous structures. These he designates by the term 'Brutbüschel,' which might perhaps be translated 'gemmiparous fascicles.' The Brutbüschel are not confined to *Scapania*, but are found also in several other genera of the leafy hepatics. They always arise from embryonic leaf-cells and consist (in their more complex forms) of branched filaments, which cut off the gemmae in basipetal succession from their tips and from the tips of their branches. In some cases the gemmae have truncate ends, showing where they were attached to their neighbors, but usually the signs of junction become obliterated and the ends appear rounded.

Buch has shown that in certain species of *Scapania* the gemmiparous function exhibits a periodicity and that the gemmiparous leaves are preceded and followed by normal leaves without gemmae. He has shown further that the gemmae are restricted to the basal portion of the first gemmiparous leaves, since this retains its embryonic character after the apical portion has reached maturity. In the succeeding gemmiparous leaves the apical portion becomes involved, and in the last gemmiparous leaves the gemmae are restricted to the apical portion, since the power to produce gemmae is lost after this portion has become differentiated. In *S. Bolanderi* the periodicity described by Buch and the changes in the position of the gemmae on the gemmiparous leaves are clearly evident.

In connection with his account of *S. irrigua* (Nees) Dumort., Buch illustrates a series of gemmiparous leaves (2, *pl. 1, f. 7–13*) and shows that

the gemmiparous function is associated with changes in the size and shape of the leaves, the most marked modifications being found in the leaves midway in the sequence. Similar modifications are present in the gemmiparous leaves of *S. Bolanderi*, as shown by figure 2, *G*. It will be seen that the lobes of this leaf are subequal in size, that the apices are distinctly pointed, and that the ciliate portion at the base of the dorsal lobe is in the form of a narrow appendage. The gemmiparous filaments in *S. Bolanderi* are restricted to the apices and sides of the marginal teeth, which tend to be longer and narrower than normal teeth, and the gemmiparous function at its height involves the whole margin from base to apex. In the leaf figured the lobes are only 1.2 mm. long by 0.6 mm. wide, but in another leaf studied they were only 0.9×0.5 mm. There are, of course, many gradations between these strongly modified gemmiparous leaves and the normal leaves without gemmae.

The inclusion of *S. Bolanderi* in the GRACILIDAE seems to be amply warranted, although the decurrence often shown by the ventral leaf-lobes represents a somewhat aberrant feature. Buch's figures of *S. gracilis* (3[2], *f. 23*) indicate a marked agreement between this species and *S. Bolanderi* in the structure of the stem and of the leaf-keels, in the features of the leaf-cells, and in the form and structure of the gemmae. There is no question, however, of a specific identity between them.

On the whole the dentation of the leaves in *S. gracilis* is less complex than in *S. Bolanderi*. In other words the teeth (as shown in fig. 3, *A*, *B*) are shorter and fewer, and the basal portion of the dorsal lobe is dentate rather than ciliate. There are also differences in the form of the lobes, which are relatively broader in *S. gracilis* than in *S. Bolanderi*. In *S. gracilis*, according to Buch, the width of the ventral lobe is 65–96 per cent as great as the length and the width of the dorsal lobe is 85–143 per cent as great. In *S. Bolanderi* the corresponding figures for the ventral lobe are 50–80 per cent and for the dorsal lobe 80–90 per cent. The squarrose habit, which the dorsal lobes of *S. gracilis* so often show, is also a distinctive feature, since the dorsal lobes of *S. Bolanderi* are more or less definitely appressed to the stem.

According to the published descriptions the mouth of the perianth in *S. gracilis* is irregularly lobed with dentate or denticulate divisions, and Buch (3,[2] p. 107) calls attention to the fact that the teeth are very often replaced by gemmiparous filaments. The perianths examined by the writer, which came from several widely scattered localities, are all gemmiparous and indicate (as shown in fig. 3, *C*) that the gemmiparous function is associated with an indefiniteness in the lobing, so that the mouth might well be described as irregularly dentate or short-ciliate. A portion of such

a mouth under a higher magnification (fig. 3, *D*) shows gemmiparous filaments like those borne on the leaf-margins and brings out the further fact that the marginal cells in the gemmiparous region are thin-walled. Müller, however, states that the cells at the mouth are often thick-walled (13, p. 196), and Buch's figure of a perianth-lobe (3^2, *f.* 23^8) shows thick-walled cells. It is evident, therefore, that the perianths of *S. gracilis* are

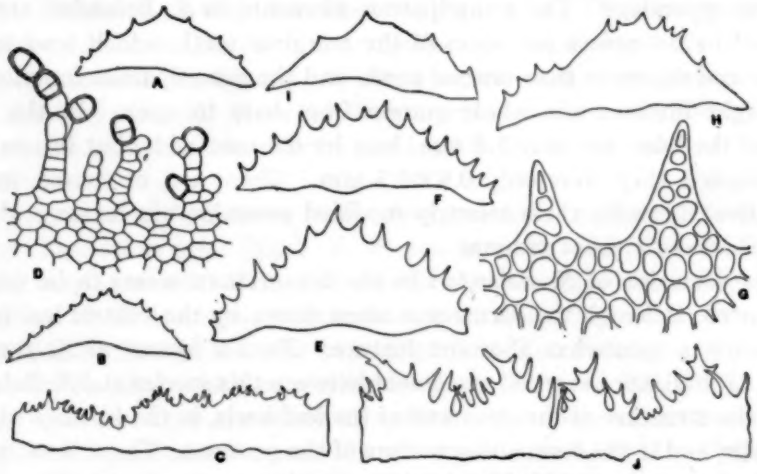

Figure 3. A-D. SCAPANIA GRACILIS (Lindb.) Kaalaas

A, B. Apices of ventral lobes, ×40. C. Teeth from mouth of perianth, ×40. D. Teeth from mouth of perianth, ×225. A was drawn from a specimen collected by Carroll on Brandon Mountain, Ireland; B, from a specimen collected by Trelease on the island of Flores, Azores (No. 1308); and C and D, from a specimen collected by Camus near Huelgoat, Finistère, France.

E-J. SCAPANIA CASARESANA Stephani

E-F. Apices of ventral lobes, ×40. G. Teeth from near apex of ventral lobe, ×225. H, I. Apices of dorsal lobes, ×40. J. Lobes and teeth from mouth of perianth, ×40. The figures were all drawn from a specimen collected by Johnson on the island of Madeira.

not invariably gemmiparous or, at any rate, not gemmiparous throughout the entire extent of their mouths. At the same time the frequency of the gemmiparous condition in the perianths of *S. gracilis* offers a further point of distinction between this species and *S. Bolanderi*, where the perianths seem to be invariably free from gemmae, even on gemmiparous plants (see fig. 2, *D*).

The known range of *S. gracilis* extends along the western coast of Europe from Norway to Spain, with an extension to the Azores, Madeira, and the Canaries. Although it has been reported from Greenland and from the eastern coast of North America, Müller (14, p. 491) points out

that these reports are all based on incorrect determinations. The species, however, may still be considered a member of the North American flora, since Buch (3[2], p. 109) reports it from the West Indian island of Guadeloupe, basing his report on specimens collected by L'Herminier. These specimens, which have not been seen by the writer, represent the type material of *S. recurva* Steph. (18, p. 146), which Müller has described and figured in his Monograph (13, p. 144, *pl. 16*). Buch, therefore, regards *S. recurva* as a synonym of *S. gracilis*.

In the southern part of its eastern Atlantic range *S. gracilis* is sometimes associated with a closely related plant which has been the cause of considerable confusion. Müller (13, p. 200) called attention to this plant in 1905 and remarked that it agreed very closely with *S. Bolanderi* under the microscope. In fact he was at first inclined to consider it identical with the Pacific Coast species. A few years later, in 1910, Stephani (18, p. 136) described it as a new species, under the name *S. Casaresana*, and reported it from Spain and Madeira. Müller, in 1915, examined authentic specimens of Stephani's species (14, p. 490) and referred them to *S. gracilis*, but Casares-Gil, in 1919, recognized the validity of the species, at least provisionally, pointing out its distinctive characters and figuring a leaf and several lobes from the mouth of a perianth (4, p. 639, *f. 331*).

In the writer's opinion *S. Casaresana* is a distinct species and is intermediate in certain respects between *S. gracilis* and *S. Bolanderi*. It shows broad leaf-lobes, as in *S. gracilis*, the dorsal lobes are often squarrose, and the teeth in the apical portions of the dorsal lobes (fig. 3, *H*, *I*) are relatively small; but the dentation of the ventral lobes, the toothed basal portions of the dorsal lobes, and the mouth of the perianth are essentially like those of *S. Bolanderi*. In figure 3, *E*, *F*, the apices of two ventral lobes from a Madeira specimen of *S. Casaresana* are shown, and in figure 3, *G*, two teeth from the apical portion of another lobe are represented under a higher magnification. These figures may be compared with figure 1, *E–I*, which illustrate corresponding structures in *S. Bolanderi*. In the same way figure 3, *J*, which represents the mouth of a perianth in *S. Casaresana*, may be compared with corresponding figures of *S. Bolanderi* (fig. 2, *A–D*). It will be noted that the perianth of *S. Casaresana* shows no signs of gemmiparous filaments, the lobes with their lateral cilia being well developed and definite in structure. In this respect also the species thus agrees with *S. Bolanderi* rather than with *S. gracilis*.

In 1897 Stephani (17, p. 82) recorded *S. Bolanderi* from Japan but afterwards decided that the Japanese specimens were distinct, giving them at first the manuscript name *S. caudata* and afterwards publishing this

species formally in 1910. Müller, however, who had seen a specimen of *S. caudata* prior to its publication, saw no reason, in 1905, for separating it from *S. Bolanderi* and confirmed the report of the latter species as a definite member of the Japanese flora.

According to Stephani the pointed leaf-lobes of *S. caudata* will distinguish the species from *S. Bolanderi*, where the lobes are said to be broadly

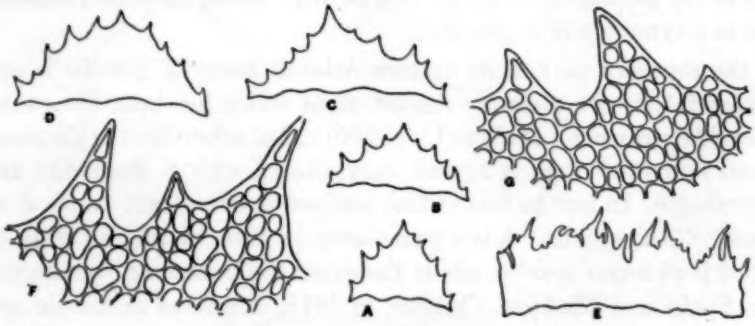

Figure 4. SCAPANIA BOLANDERI Austin

A-D. Apices of ventral lobes, ×40. E. Lobes and teeth from mouth of perianth ×40. F, G. Teeth from near apices of ventral lobes, ×225. A, B, and G were drawn from a specimen collected by Faurie on Mt. Hayachine, Japan (No. 14413); and C-F, from a specimen collected by Faurie near Takachi, Japan (No. 1846).

rounded at the apex. In the writer's experience the apices, in both American and Japanese specimens, are subject to considerable variation. In figure 4, for example, the apices of four ventral lobes from Japanese material are illustrated, and these may be compared with the apices from American material illustrated in figure 1. The lobes shown in figure 4, *A–C*, are distinctly pointed, but the lobe shown in figure 1, *G*, is hardly less so. In the same way the lobe shown in figure 1, *E*, is approximated by the one shown in figure 4, *D*, although broader and still more rounded lobes might have been selected from the Japanese material. There are thus no essential differences in the lobes between *S. caudata* and *S. Bolanderi*. The resemblance in the perianths is equally striking, when the mouth from a Japanese specimen (fig. 4, *E*) is compared with mouths from American material (fig. 2, *A–C*).

Stephani alludes also to a difference in the size of the leaf-cells. According to his descriptions the marginal cells of *S. Bolanderi* are only 18 microns in diameter, while those of *S. caudata* are 27 microns. The marginal teeth illustrated in figure 4, *F*, *G*, which were drawn from the ventral lobes of Japanese specimens, show cells which appear, if anything, smaller than those in the American specimens (fig. 1, *H*, *I*), although the

actual measurements are in essential agreement. The writer would therefore agree with Müller in considering *S. caudata* Steph. a simple synonym of *S. Bolanderi*. Perhaps in time the species may be found along the Asiatic coast north of Japan.

II. Scapania americana

Scapania americana K. Müll. Bull. Herb. Boissier II. 3: 44. 1903.

This interesting species was based on two specimens collected by Miss Gertrude Gibbs at Port Renfrew, Vancouver Island, but these specimens do not show the species in its most luxuriant development. As a result *S. americana* has been imperfectly understood, and characteristic specimens have been referred to the common and widely distributed *S. nemorosa* (L.) Dumort. It is doubtful, however, if the true *S. nemorosa* occurs at all in western North America. The following specimens of *S. americana* have been examined:

Alaska: McDonald Lake region, 1905, *J. S. Burcham 141*; Aats Bay, 1913, *T. C. Frye 938*, listed by the writer (8, p. 606) as *S. nemorosa*.

British Columbia: Goldstream, Vancouver Island, 1893, *J. Macoun 36-43, 51-66*, listed by Macoun (11, p. 39) as *S. nemorosa*; Port Renfrew, Vancouver Island, 1901, *G. Gibbs 57, 117*, the type-locality; Foul Bay, Sydney, 1913, *J. Macoun*; Shell Island, Beaver Bay, Queen Charlotte Sound, 1913, *T. C. Frye 1142*.

Washington: rock walls of Merryetta Gorge, Hamilton, 1904, *A. S. Foster 26*; Orcas Island, no date, *A. M. Dougherty 32*; same locality, 1925, *L. Clark 135*; Trout Lake, Friday Harbor, 1925, *L. Clark 132*; northern end of Reservation, no date, *L. Clark 138*.

Oregon: Spencer's Butte, no date, *H. R. Hayden 148*, listed by Miss Sanborn (16, p. 79) as *S. nemorosa*.

California: Mt. Tamalpais, 1893, *M. A. Howe 21*; near Lake San Andreas, San Mateo County, 1895, *M. A. Howe 1192*; Cazadero, Sonoma County, 1896, *M. A. Howe 1191*; Lake Lagunitas, Marin County, 1896, *M. A. Howe* (N. Y.); Gasquet Mountain, Del Norte County, 1923, *A. Eastwood 30*. The first four specimens are listed by Howe (10, p. 150) as *S. nemorosa*.

According to the available data *S. americana* does not occur on logs, stumps, or trees but is confined to rocks, banks, and shaded soil, where it sometimes forms pure mats and sometimes grows in admixture with other bryophytes. It varies in color from green to rich golden brown and occasionally shows a purplish or reddish tinge. The branching is scanty and irregular.

As in *S. Bolanderi* and many other species of the genus the stems tend to be more deeply pigmented than the leaves and are often very dark. Cross-sections (fig. 5, *A*, *B*) show a well-marked cortex, rather sharply marked off from the colorless or very pale medulla. This cortex is inter-

rupted ventrally, just as in *S. Bolanderi*, and a pale narrow longitudinal band is often apparent in intact stems. The cortical cells are in two to five layers, and their walls are strongly thickened and usually deeply pigmented. As a rule the boundaries between the cells are not clearly marked. The walls show a rich golden brown coloration, and the bounding

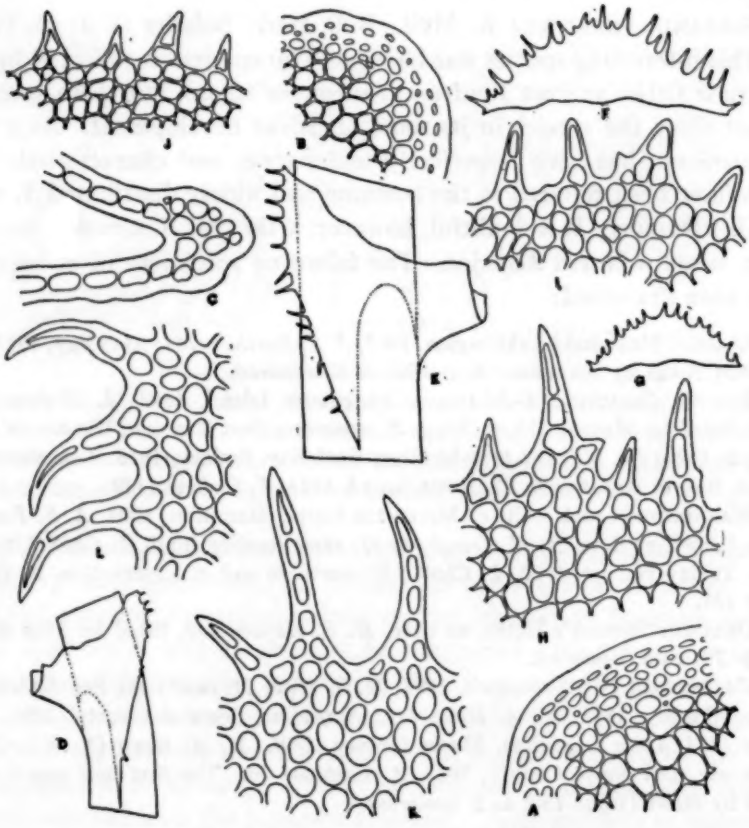

Figure 5. SCAPANIA AMERICANA K. Müller

A, B. Cross-sections of stems, dorsal and lateral portions, ×225. C. Cross-section of keel of leaf, ×225. D. Base of ventral lobe from a slender stem, ×40. E. Base of ventral lobe from a more robust stem, ×40. F, G. Apices of ventral lobes, ×40. H-K. Teeth from apical portions of ventral lobes, ×225. L. Teeth from margin of ventral lobe, about midway between apex and base, ×225. A, C, F, and H were drawn from a specimen collected by Frye at Aats Bay, Alaska (No. 938); B, from a specimen collected by Howe near Lake San Andreas, San Mateo County, California (No. 21); D, I, and J, from a specimen collected by Miss Gibbs at Port Renfrew, British Columbia (No. 57); E, K, and L, from a specimen collected by Foster at Hamilton, Washington (No. 26); and G, from a specimen collected by Miss Gibbs at Port Renfrew, British Columbia (No. 117).

walls on the outside are often paler than the others, although a difference in shade is by no means always apparent. The bounding walls form a more or less continuous membrane, often as much as 10 microns in thickness, and the cavities of the outside layer are frequently reduced to narrow slits, much as in *S. Bolanderi*. The medullary cells usually show minute triangular thickenings at the angles, but are otherwise thin walled. In the medullary cells measured the diameters averaged about 17 microns, and in the cortical cells the tangential width averaged about 11 microns, so that the ratio between the cells is about the same as in *S. Bolanderi*.

Müller's plate (13, *pl. 19b*) gives an excellent idea of the type-specimens, and Miss Sanborn's figures (16, *pl. 5, f. 3*) show clearly the general habit of a more robust plant and the structure of the foliar teeth. The leaves are approximate or more or less imbricate. The keel (fig. 5, *C*), which is usually one third to one half as long as the ventral lobe, shows the same structure as that of *S. Bolanderi*, being about four cells thick and usually wingless, although narrow wings can occasionally be demonstrated. The keel spreads at an angle of 60–90 degrees and is either straight throughout or slightly arched in the outer part. The walls of the keel-cells are much like those of *S. Bolanderi*.

The ventral leaf-lobes spread widely and are often so convex that they give the impression of being more widely separated than they really are. They are ovate to obovate in form and measure 1–2 mm. in length by 0.75–1.2 mm. in width. The line of attachment to the stem (fig. 5, *D*, *E*) arches forward from the keel and then curves sharply backward, usually extending considerably beyond the level of the keel. In many cases the lobe is slightly revolute in the lower part. The apices of the lobes (fig 5, *F*, *G*) are broad and rounded, and the whole margin is sharply and closely dentate-ciliate. The teeth vary markedly in length and, according to Stephani (18, p. 136), large teeth and small teeth alternate. This condition is shown in figure 5, *H*, but is by no means constant, as is evident from the teeth shown in figure 5, *I–K*. The smallest teeth consist of single, sharp-pointed cells, and the largest are five cells long and three cells wide at the base, the tip being composed of a cell-row of three or four cells; between these extremes are all possible gradations. The unicellular teeth and the terminal cells of the multicellular teeth are considerably longer than broad. It may be noted also that the apical tooth, except by its position, is indistinguishable from the others; that an occasional tooth on a robust individual may give off a short supplementary tooth near the base (see fig. 5, *H*, *I*); and that the teeth on the ventral side of the lobe (fig. 5, *L*) are sometimes bent or curved backward.

According to Müller the dorsal lobe is nearly as large as the ventral,

but the measurements indicate a somewhat smaller size. In the specimens examined by the writer the length is 0.7–1.3 mm. and the width 0.45–1.2 mm. The lobes are slightly convex and are either appressed to the stem or more or less squarrose. They arch across the stem and usually considerably

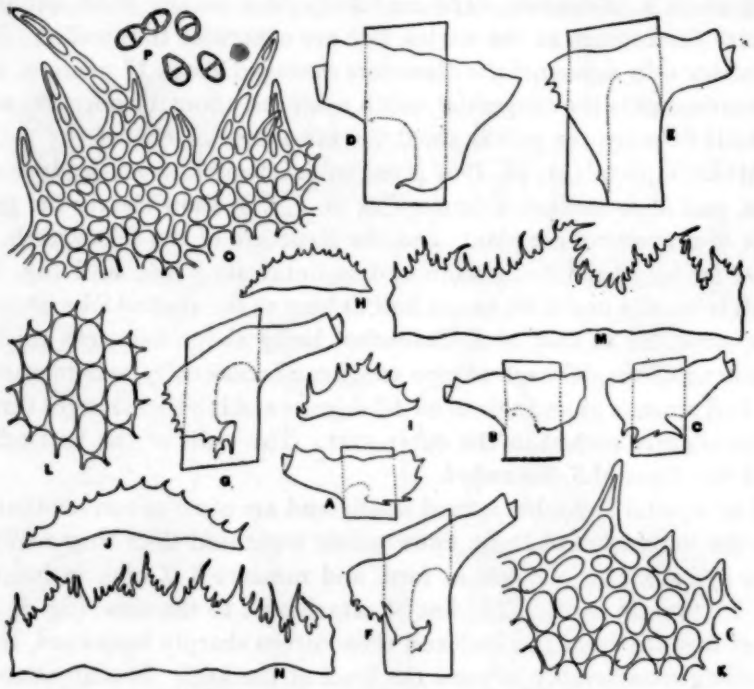

Figure 6. SCAPANIA AMERICANA K. Müller

A-G. Bases of dorsal lobes, ×40. H-J. Apices of dorsal lobes, ×40. K. Apex of dorsal lobe, ×225. L. Cells from median region of ventral lobe, ×225. M, N. Lobes and teeth from mouths of perianths, ×40. O. Teeth from mouth of perianth, ×225. P. Gemmae, ×225. A-C, H, and I were drawn from a specimen collected by Miss Gibbs at Port Renfrew, British Columbia (No. 117); D, J-L, and O, from a specimen collected by Frye at Aats Bay, Alaska (No. 938); E, from a specimen collected by Miss Clark at the northern end of Reservation (No. 138); F and G, from a specimen collected by Foster at Hamilton, Washington (No. 26); M and N, from a specimen collected by Miss Clark at Friday Harbor, Washington (No. 132); and P, from a specimen collected by Howe near Lake San Andreas, San Mateo County, California (No. 21).

beyond and vary in form from broadly ovate to orbicular. The basal portion and the line of attachment to the stem are subject to marked variation. In some cases the line is much the same as in *S. Bolanderi*. Under these circumstances (fig. 6, *A–C*) it starts almost transversely from the base of the keel or arches slightly toward the stem-apex and then,

curves backward, ending at about the level with the keel. In other cases, as shown in figure 6, *D–G*, there is definite decurrence, the line extending a considerable distance beyond the end of the keel. Aside from the differences just described there are striking differences in the form and dentation of the basal portion of the lobe. In its simplest manifestations the base narrows gradually and is entire or nearly so (fig. 6, *E*); at the other extreme the base is dentate and more or less plicate and may even show minute lobules or auricles of various kinds (fig. 6, *F*, *G*). In these more complex types the basal dentation is often marked, although the teeth tend to be shorter than those of the ventral lobe. Some of the teeth may extend backward, as in *S. Bolanderi*, but the basal portions of the lobes in *S. americana* never attain the extreme complexity which those of the commoner species often show. Aside from the basal teeth the dorsal lobes of *S. americana* (fig. 6, *H–J*) develop scattered teeth, similar to those of the ventral lobe but tending to be fewer and shorter. Some of the unicellular teeth, in fact, consist of projections of cells and not of entire cells (fig. 6, *K*).

The leaf-cells average about 15 microns along the margin of the ventral lobe, 25×18 microns in the middle, and 32×20 microns at the base. Distinct trigones are present in the median (fig. 6, *L*) and basal portions and may show slightly bulging sides. They are usually less well developed, however, than in *S. Bolanderi*. Toward the margin the trigones are coalescent, and the walls of two to five rows of cells usually present the appearance of being uniformily thickened (figs. 5, *K*, and 6, *K*). The cuticle is commonly more or less distinctly verruculose or striate-verruculose but is sometimes smooth or nearly so. The oil bodies have not yet been studied.

The male bracts of *S. americana* are not much differentiated. They show clusters of antheridia in their axils, mixed with filamentous or narrowly lanceolate paraphyses, and similar organs are sometimes present in the axils of other leaves.

The mouth of the perianth sometimes shows large and distinct lobes with lateral and terminal cilia, as represented in figure 6, *M*, but there are all gradations between these large lobes and simple cilia, as shown in this same figure and also in figure 6, *N*. The cilia, whether borne on the tips or margins of the lobes or arising independently (fig. 6, *O*) are much like the cilia or teeth on the ventral lobes but tend to be longer and even more densely crowded. In cases where the perianths are more or less aborted the conditions are simpler than those just described, the cilia being shorter and less numerous. No cases have been observed, however, in which these aborted perianths had given rise to gemmae.

Although the specimens of *S. americana* are often free from gemmae,

these have been observed in material from several widely scattered localities. They are produced in considerable abundance, but the gemmiparous leaves do not show the marked modifications noted under *S. Bolanderi*. The gemmae (fig. 6, *P*) are mostly 20–26 microns long by 12–14 microns wide and are normally two-celled, the dividing wall being thin and the bounding wall somewhat thickened. The walls show a golden brown pigmentation, sometimes tinged with purplish, and the gemmae are broadly ovate in outline, tending to narrow somewhat toward the ends, which are sometimes distinctly truncate.

It will be seen, from the preceding account, that *S. americana* bears a certain resemblance to *S. Bolanderi*. The most important of its distinctive features are perhaps the following: the foliar teeth are numerous and crowded and in the form of narrow triangles with slender apices; the ventral lobe is distinctly decurrent, and the dorsal lobe is sometimes decurrent also; the basal portion of the dorsal lobe varies from entire to variously short-dentate; the mouth of the perianth is divided into narrow and crowded ciliate lobes, associated in many cases with separate cilia; and the gemmae have pigmented walls. In *S. Bolanderi* the foliar teeth are fewer and more scattered and are in the form of broader triangles with blunter apices; the ventral lobe is less decurrent, and the dorsal lobe is scarcely or not at all decurrent; the basal portion of the dorsal lobe is usually densely ciliate; the mouth of the perianth is more coarsely lobed, and the cilia along the sides of the lobes are less densely crowded; and the gemmae are not pigmented.

In *S. nemorosa*, with which *S. americana* has been confused, we have a variable species which approaches the western species only in its more robust forms. In these the foliar teeth, although slender and sharp-pointed are less crowded than in *S. americana* and are rarely more than two cells long. The plants are further distinguished by the thinner stem-cortex and the greater contrast in size between the cortical and medullary cells; by the constant lack of teeth in the basal portion of the dorsal lobe; by the ciliate or dentate mouth of the perianth, which shows no indication of lobing; and by the one-celled gemmae. The robust forms of *S. nemorosa* vary towards forms with smaller and more scattered teeth, which tend in certain extreme cases to disappear altogether. Such forms, of course, could hardly be confused with *S. americana*.

Müller was at first somewhat uncertain about the taxonomic position of *S. americana*. In his original description (12, p. 44) he compares it with *S. gracilis* but implies that the relationship between the two species is not especially close. In his monograph, however, he places *S. americana* next to *S. gracilis* in his group NEMOROSA (13, p. 201) and a few years later

mentions both *S. americana* and *S. Bolanderi* as close allies of *S. gracilis* (14, p. 491). Buch, in his classification, places *S. americana* provisionally in the section GRACILIDAE (3, p. 110, footnote), on the basis of Müller's description and figures, but from a subsequent study of the original specimens he is now inclined to the opinion that the mode of attachment of the leaves would exclude it from this section. He points out the resemblance between *S. americana* and *S. nemorosa* but does not assign the American species to his section NEMOROSAE. In the writer's opinion, however, it fits better into this section than into any of the other sections proposed by Buch. The two-celled gemmae represent what is perhaps the most aberrant feature, the gemmae in all the other species of the NEMOROSAE (so far as known) being one-celled. But this single difference would hardly be sufficient to exclude *S. americana*, since other sections, such as the CURTAE and the IRRIGUAE, show gemmae of both types.

III. SCAPANIA GRANULIFERA

The species which Buch includes in his section AEQUILOBAE are all characterized by a coarsely papillose or verrucose cuticle, at least in the median and basal portions of the leaf-lobes. The cuticular outgrowths lend the surface a satin-like appearance and tend to obscure the outlines of the cells underneath. The section is further distinguished by a stem-cortex composed of two to four layers of thick-walled cells, by the decurrence of both ventral and dorsal lobes, by more or less scattered foliar teeth tipped with cells perhaps twice as long as broad, by ciliate lobes at the mouth of the perianth, and by two- to four-celled gemmae.

Two species of this section, *S. aequiloba* (Schwaegr.) Dumort. and *S. Simmonsii* Bryhn & Kaalaas, have been reported by Bryhn (1, pp. 50, 51) from Ellesmere Island, west of Greenland, but these are the only definite records for the AEQUILOBAE from North America. In his description of *S. nemorosa*, however, Howe (10, p. 150) states that 'the cuticle in the California specimens is for the most part distinctly granulate or verruculose.' The writer has examined the various specimens listed by Howe, and finds that the cuticle in all except one is verruculose or striate-verruculose, rather than granulate. These specimens are cited above under *S. americana*. In the exceptional specimen, which was collected in Del Norte County, by Howell, the cuticle is distinctly granulate or verrucose. This specimen agrees with the later and more abundant specimens collected by Miss Eastwood in the same county, and the species described below is based on this combined material. Although the leaves are more densely ciliate-dentate than in any of the AEQUILOBAE described by Buch, the taxonomic position of the new species is clearly in this section.

Scapania granulifera sp. nov.

Plants growing in depressed or ascending mats, sometimes in pure colonies and sometimes mixed with other bryophytes, pale or bright green, varying to yellowish green or yellowish brown: stems usually dark brown and sometimes appearing almost black, mostly 3–5 cm. long and 0.25–0.5 mm. in diameter, simple or sparingly and irregularly branched, usually free from rhizoids in the upper part; cortex mostly two to four cells thick, passing rather gradually into the medulla, cortical cells averaging about 13μ in tangential diameter, with very thick walls appearing golden brown in thin sections, the surface-walls sometimes a little paler than the others, medullary cells averaging about 18μ in diameter, the walls pale yellowish to colorless, thin, except for the triangular thickenings at the angles: leaves approximate to more or less imbricate; keel one-fifth to one-fourth as long as the ventral lobe, forming at the base an angle of 45–60 degrees with the stem, approximately straight or somewhat arched, the angle with the stem thus being increased to about 90 degrees, usually wingless, about four cells thick from top to bottom, the cells bounded on the outside by strongly thickened walls but separated from one another by thinner walls; ventral lobe widely spreading, strongly convex and often narrowly revolute near the ventral base, ovate to obovate, mostly 1.5-2 mm. long and 0.75-1.2 mm. wide, distinctly decurrent, the whole margin densely dentate or dentate-ciliate; dorsal lobe broadly ovate to suborbicular, mostly 0.75–1.2 mm. long and 0.75–0.9 mm. wide, less widely spreading than the ventral lobe, convex, more or less appressed to the stem or somewhat squarrose, arching considerably beyond the stem, the margin dentate or dentate-ciliate but the teeth tending to be shorter than those of the ventral lobe, distinctly decurrent, the basal portion variously toothed; leaf-cells averaging about 10μ at the margin of the lobes, 23$\times$17μ in the middle, and 31$\times$17μ at the base, with distinct trigones except in the marginal region, cuticle verrucose: inflorescence dioicous: ♂ inflorescence at first terminal but often later intercalary; bracts imbricate, in many pairs (sometimes twenty or more), more or less saccate at the base but otherwise much like the vegetative leaves; antheridia clustered, mixed with filamentous or narrowly lanceolate paraphyses: ♀ inflorescence not innovating (in the few examples studied); bracts a little larger than the vegetative leaves and less decurrent but otherwise very similar, the ventral lobe measuring about 2$\times$1.4 mm. and the dorsal about 1.5$\times$1 mm., keel about one-third as long as the ventral lobe; perianth oblong from a narrow base, scarcely narrowed at the mouth, flattened and without dorsal or ventral keels, about 3 mm. long and 1.8 mm. wide, the mouth with crowded and irregular ciliate lobes: gemmae unknown.

CALIFORNIA: near Crescent City, April, 1892, *T. Howell* (N. Y.), listed by Howe (10, p. 150) as *S. nemorosa*; along Skelly Creek, August 6, 1923, *A. Eastwood 19*;

Patrick Creek, same date, *A. Eastwood 33*; between Crescent City and Adams, August 11, 1923, *A. Eastwood 1*. The stations are all situated in Del Norte County and No. 19 was collected 'on wet banks.' No. 1 may be designated the type.

The line of attachment of the ventral lobe in *S. granulifera* (fig. 7, *C*) curves upward from the base of the keel and then arches downward in an

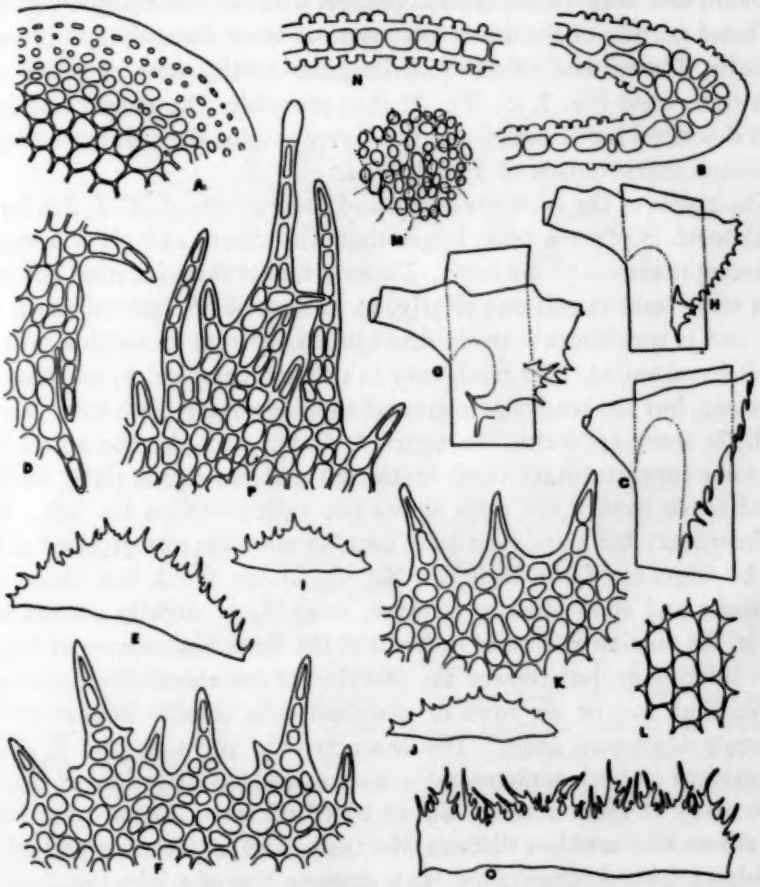

Figure 7. SCAPANIA GRANULIFERA Evans

A. Cross-section of stem, dorsal portion, ×225. B. Cross-section of keel of leaf, ×225. C. Base of ventral lobe, ×40. D. Teeth from near base of ventral lobe, ×225. E. Apex of ventral lobe, ×40. F. Apex of ventral lobe, ×225. G, H. Bases of dorsal lobes, ×40. I, J. Apices of dorsal lobes, ×40; K. Apex of dorsal lobe (apical tooth at left), ×225. L. Cells from median region of ventral lobe, ×225. M. Cells from same general region as L, showing surface-verrucae, ×225. N. Cells of ventral lobe in cross-section, ×225. O. Lobes and teeth from mouth of perianth, ×40. P. Teeth from mouth of perianth, ×225. The figures were all drawn from the type-specimen.

almost straight direction, extending considerably below the level of the keel. The line of attachment of the dorsal lobe might be described in almost the same way, except that the degree of decurrence is a trifle less. The decurrent portion of the ventral lobe narrows gradually and is normally dentate-ciliate. In many cases some or all of the teeth curve backward and may extend almost parallel with the leaf-margin (fig. 7, *D*). The basal portion of the dorsal lobe narrows more abruptly and is usually variously dilated and lobed, with irregular teeth, some of which often point downward (fig. 7, *G*, *H*). It thus resembles the more complicated types described for *S. americana* but never attains the still more complex conditions characteristic of *S. Bolanderi*.

The apices of the lobes are broad and rounded (fig. 7, *E*, *I*, *J*,), but the apical tooth is often a trifle larger than the others and gives a vaguely pointed appearance to the lobes. Under a higher magnification the apical tooth sometimes stands out clearly, as in figure 7, *F* (second tooth from left), and is sometimes scarcely distinguishable from its neighbors (fig. 7, *K*, left-hand tooth). The teeth vary in size and complexity, much as in *S. americana*, but the tendency to give off supplementary teeth from the sides is a little more apparent. In figure 7, *F*, for example, the apical tooth shows one supplementary tooth on the left and two on the right, while the second tooth toward the right shows one such tooth on the left. These supplementary teeth are sometimes nothing more than projections of cells.

The trigones of the leaf-cells (fig. 7, *L*) are much like those of *S. americana* and show slightly concave, straight, or slightly convex sides; even in the median and basal portions of the lobes coalescence of trigones is not infrequent, but toward the margin the coalescence becomes so extensive that five or six rows of marginal cells usually appear to have uniformly thickened walls. The characteristic verrucae (fig. 7, *M*) are very evident on both surfaces in the median and basal portions of the lobes where many of them attain a size of 10×8 microns. Toward the margin they are smaller and less distinct, the teeth and adjacent marginal cells acquiring a frosted appearance. In a cross-section of a lobe (fig. 7, *N*) the verrucae are in the form of slightly flattened circles, the height of which is about as great as the thickness of the walls. A cross-section of a keel (fig. 7, *D*) brings out the fact that the verrucae may be absent in the vicinity of the curvature. The oil bodies of the species are still unknown.

The mouth of the perianth in *S. granulifera* (fig. 7, *O*) shows a series of densely crowded, narrow and irregular lobes associated with simple cilia. The lobes run out into slender points and bear cilia or teeth on their sides (fig. 7, *P*). No evidence has been obtained that the perianth-mouth is

ever gemmiparous. In fact the gemmae of the species have not yet been demonstrated.

In general appearance *S. granulifera* resembles the more robust forms of *S. americana*, and the two species might easily be confused in the field. Under the microscope, however, the conspicuous verrucae will at once distinguish *S. granulifera*, and the smaller marginal leaf cells yield another important difference. At the same time certain of the morphological features of *S. granulifera* are much like those of *S.americana*. The stem-

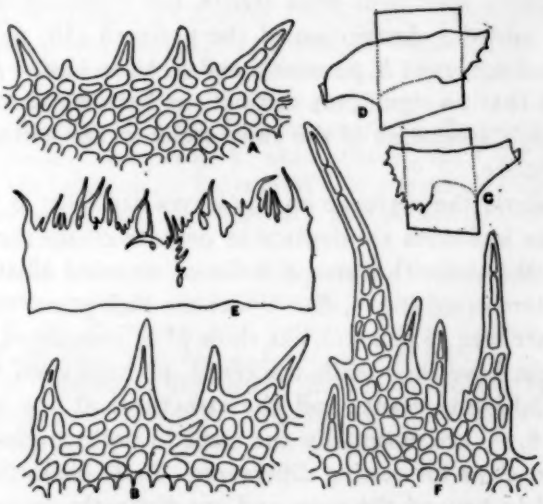

Figure 8. SCAPANIA PARVITEXTA Stephani

A, B. Teeth from near apices of ventral lobes, ×225. C, D. Bases of dorsal lobes, ×40. E. Lobes and teeth from mouth of perianth, ×40. F. Teeth from mouth of perianth, ×225. A and C were drawn from a specimen collected by Faurie near Hakodate, Japan (No. 20); and B and D-F, from a specimen collected by Faurie near Aomori, Japan, and distributed as '*S. hirosakiana*' (No. 131).

structure, for example, as shown in figure 7, *A*, agrees closely with that of *S. americana*, as shown in figure 5, *A*, *B;* and the same thing is true of the structure of the foliar keels. The foliar teeth and the perianth-mouths are also very similar and yet offer a few disinctions, the foliar teeth of *S. granulifera* showing a greater tendency to bear supplementary teeth, and the lobes at the mouth of the perianth tending to be more crowded, narrower, and less complex. Other resemblances and differences have already been pointed out.

The present species need hardly be compared with *S. aequiloba* or *S. Simmonsii*, since both of these species have fewer and shorter foliar teeth.

It bears a marked resemblance, however, to a Japanese member of the AEQUILOBAE, which Stephani (17, p. 107) described under the name *S. parvitexta*. This species, which has been collected at several stations by Faurie, was afterwards redescribed and figured by Müller (13, p. 158, *pl. 26b*). In the writer's opinion another Japanese species, *S. hirosakiensis* Steph., should be considered a synonym of *S. parvitexta*. This species, which also was based on Faurie's material, was named in manuscript by Stephani and sent to Müller, who published it in his Monograph (13, p.120, *pl. 11a*). Müller's specimens were sterile, but Stephani, in his Species Hepaticarum, added a description of the perianth (18, p. 150). If the descriptions and figures of *S. parvitexta* and *S. hirosakiensis* are compared, it will be seen that no significant distinctions between them are brought out, and Faurie's specimens of the two species in the writer's herbarium are essentially alike.

In *S. parvitexta* the verrucae on the leaves are fully as large as in *S. granulifera*, the leaf-lobes are dentate or dentate-ciliate throughout, and the mouth of the perianth shows a series of crowded ciliate lobes, with simple cilia interspersed (fig. 8, *E*). Under the high power the foliar teeth (fig. 8, *A*, *B*) are seen to be much like those of *S. granulifera*, the leaf-cells near the margin have their walls thickened, perhaps even more strongly than in the California plant, and the structures at the mouth of the perianth (fig. 8, *F*) are essentially the same in both species. The dorsal lobes, however, show interesting differences. In *S. granulifera* the dorsal lobes arch widely beyond the stem and are distinctly decurrent, the line of attachment extending considerably beyond the level of the keel; but in *S. parvitexta* the lobes extend only slightly beyond the stem and are not at all decurrent, the line of attachment ending at about the level of the keel. The base of the lobe, moreover, varies from rounded (fig. 8, *D*) to distinctly auriculate (fig. 8, *C*).

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Note on the tissue fluids of Phoradendron juniperinum parasitic on Juniperus utahensis

J. Arthur Harris,* Truman A. Pascoe, and Ivan D. Jones

Earlier studies on the osmotic concentration of the tissue fluids of mistletoes parasitic on various angiosperms have included both the Jamaican montane rain forest[1] and the mountains and deserts of Arizona.[2] The results indicate that in both the rain forest and the desert the osmotic concentration of the tissue fluids of the parasite is generally, but not invariably, higher than that of the host. The exceptions have been discussed and the earlier literature reviewed in the papers cited. It has also been shown that the electrical conductivity of the tissue fluids of desert Loranthaceae is higher than that of their hosts.[3] It has seemed desirable to extend these determinations to include a quite different species of parasite and host.

RESULTS

Juniperus utahensis (Engelm.) Lemmon, sometimes with an admixture of Piñon Pine, forms the lowest forest zone on the outwash slopes of the Wasatch and other mountains of the Great Basin in Utah. It is known from our earlier work to be a species of relatively high osmotic concentration. In certain areas *Phoradendron juniperinum* Engelm. is abundant as a parasite.

Table 1 gives the results of a series of determinations made by the cryoscopic and electrometric methods employed and fully described in papers on other series of determinations on plant tissue fluids. The chloride contents were determined by a method due to Lawrence.[4]

* The sad report of the sudden death of Professor Harris at Minneapolis, 24 April 1930, was received a few days in advance of the proofs of this paper.

[1] **Harris, J. Arthur, and J. V. Lawrence.** The osmotic pressure of the tissue fluids of Jamaican rain forest Loranthaceae parasitic on various hosts. Amer. Jour. Bot. **3**: 438–455. 1916.

[2] **Harris, J. Arthur.** On the osmotic concentration of the tissue fluids of desert Loranthaceae. Mem. Torrey Club **17**: 307–315. 1918.

[3] **Harris, J. Arthur, and A. T. Valentine.** The specific electrical conductivity of the tissue fluids of desert Loranthaceae. Proc. Soc. Exp. Biol. Med. **18**: 95–97. 1920.

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TABLE 1

Comparison of tissue fluid properties of Phoradendron juniperinum parasitic on Juniperus utahensis

	FREEZING POINT DEPRESSION IN DEGREES Δ	OSMOTIC CONCENTRATION IN ATMOSPHERES P	SPECIFIC ELECTRICAL CONDUCTIVITY κ	RATIO OF CONDUCTIVITY TO DEPRESSION κ/Δ	CHLORIDE CONTENT IN GM. PER LITER Cl.
C28625					
Parasite	2.33	28.0	.02232	.00959	1.95
Host	1 76	21.2	.01005	.00570	1.63
Difference	+ .57	+ 6.8	+.01227	+.00389	+ .32
C28626					
Parasite	2.10	25.2	.02369	.01128	1.51
Host	1.93	23.2	.00976	.00505	.98
Difference	+ .17	+ 2.0	+.01393	+.00623	+ .54
C28627					
Parasite	2.23	26.8	.02369	.01063	1.15
Host	2.09	25.1	.00900	.00430	.71
Difference	+ .14	+ 1.6	+.01469	+.00633	+ .44
C28640					
Parasite	2.52	30.2	.02662	.01058	1.69
Host	2.34	28.1	.00936	.00400	1.08
Difference	+ .18	+ 2.1	+.0.726	+.00657	+ .61
C29114					
Parasite	2.13	25.6	.02081	.00976	
Host	1.96	23.5	.01489	.00760	
Difference	+ .17	+ 2.1	+.00593	+.00216	
C29117					
Parasite	2.18	26.2	.01962	.00900	1.55
Host	1.45	17.5	.00951	.00654	1.21
Difference	+ .73	+ 8.7	+.01012	+.00246	+ .35
C29226					
Parasite	2.08	24.9	.01398	.00673	
Host	1.89	22.7			
Difference	+ .19	+ 2.3			
C29545					
Parasite	2.04	24.6	.01998	.00977	1.35
Host	1.71	20.6	.00983	.00578	.46
Difference	+ .33	+ 4.0	+.01010	+.00400	+ .89

The first column of the table gives the sample number of parasite and host.[5] The entries in the second and third columns show that in all cases the freezing point depression, Δ, and the osmotic concentration, P, calculated from the freezing point depression, is higher in the tissue fluids of the parasite than in those of its host. The differences range from 0.14° to 0.73° and from 1.62 to 8.71 atmospheres. The averages of the eight pairs of determinations are

For parasites	26.44
For host	22.73
Difference	3.70

Applying the method proposed by "Student"[6] we find $z=1.50$, $p=.9973$. Thus the odds are roughly 400:1 that the difference is statistically significant.

A study of the individual constants suggests that the parasite is more stable in the osmotic concentration of its tissue fluids than the host.

This impression is confirmed by the determination of the standard deviations of the osmotic pressures, which are 1.76 for the parasite as compared with 2.96 for the host. Thus the absolute variability of the osmotic concentration of the parasite is less than that of the host. The relative variability as measured in terms of the coefficients of variation are 6.64 for the parasite as compared with 13.01 for the host. Before much importance is attached to these results they must be confirmed by more extensive data. In the meantime they suggest that the tissue fluids of the mistletoe are less subject to the influence of environmental conditions than are those of the host. That the concentration of the tissue fluids of the parasite is not independent of that of the host is indicated by a correlation of $+ \cdot 55$ between the two measurements of the values of P.

The electrical conductivities, κ, of the tissue fluids of the parasites are in all cases higher than those of the hosts. Unfortunately the electrical conductivity for the host could not be obtained in one case (C29226) while in another (C29114) the conductivity of the host is so high that legitimate question may be raised as to possible error of determination. In this instance the chloride content could not be determined, since the

[5] The first two figures of these numbers designate the year. The locations and dates of collection are: C28625–C28627, Western slope of Standsbury Mts., August 6; C28640, Near Lofgreen, Tintic Mts., August 7; C29114, C29117, West slope of Povant Mt., July 6; C29545, same habitat as C29117, August 18; C29226, Near Garden City, July 18.

[6] "Student." The probable error of the mean. Biometrika 6: 1–25. 1908.

fluids were required for other purposes. The average for the seven available pairs are

For parasite	.02239
For host	.01035
Difference	.01204

As far as the results go, they fully confirm earlier findings for a higher electrolyte content of the tissue fluids of the mistletoe.

Six comparisons of the chloride content (in terms of grams of Cl per liter) are available. These show that in every case the tissue fluids of the parasite have a higher content of the ion. The averages are

For parasite	1.535
For host	1.010
Difference	0.525

This result should not be presented without noting that other species of mistletoes and hosts in other regions have been found to furnish exceptions to the present results for a higher chloride content of the parasite. Possibly it is only when the chloride content of the tissue fluids of the host is very low that it is exceeded by that of the parasite.

SUMMARY

An investigation of the tissue fluid properties of *Phoradendron juniperinum* parasitic on *Juniperus utahensis* in the lowest forest zone of the Great Basin shows that the freezing point depression, osmotic concentration calculated from the freezing point depression, specific electrical conductivity, and chloride content of the mistletoe are higher than those of the host.

A method of obtaining pure cultures of Spirodela polyrhiza

ALBERT SAEGER

Recently there has been a renewed interest in the study of the physiology of the Lemnaceae (Duckweeds). *Lemna minor* L. and *Spirodela polyrhiza* (L.) Schleiden are the two species that have been most commonly used in the investigations of Bottomley (1917, 1920), Mendiola (1919), Mockeridge (1920, 1924, 1927), Clark and Roller (1924), Clark (1924, 1925, 1926), Saeger (1925, 1929), Deuber (1926), Ashby, Bolas, and Henderson (1928), Su and Ashby (1929), and Ashby (1929).

Some of the studies have dealt with the part played by small amounts of substances in the nutrition of these plants—'auximones,' stimulants, iron. Where the effect of small quantities of materials upon the growth of higher plants is concerned, bacterial contamination of the cultures may be a disturbing factor, especially where organic matter is added. The methods of obtaining sterile cultures by seed disinfection are not applicable to all species of duckweeds. Although *L. minor* produces seed quite commonly, *S. polyrhiza* blooms but rarely (Saeger, 1929), and fully matured seeds have not often been collected. The sterilization of entire plants in the vegetative condition is not readily accomplished.

Hansteen (1896, 1899) claimed to have grown *L. minor* under sterile conditions in solutions of tap water containing various organic substances (amino acids, urea, glucose). He rinsed the plants in sterilized distilled water. Failure of the solutions to become turbid was taken as indication that they were sterile. Mameli and Pollacci (1910, 1914) reported a method of sterilizing living plants of *Lemna major* Griff. (*S. polyrhiza*), using hydrogen peroxide. They claimed to have obtained complete sterilization without injury to the plants by exposure to a 3 per cent solution of hydrogen peroxide for one minute.

Attempts of the writer to free the duckweeds of micro-organisms by rinsing with sterile water always resulted in failure. It was also found that when entire plants of *Spirodela* were exposed to a 3 per cent solution of hydrogen peroxide for five minutes, some were killed, all were severely injured, and those that survived were not sterile. Attempts to sterilize the plants by exposure to mercuric chloride (1:1000), to 0.25 per cent Semesan (a disinfectant containing 30 per cent hydroximercurichlorophenol sulphate), and to copper sulphate (1:2,000,000) were unsuccessful.

After these trials attempts were made to sterilize the resting buds of *Spirodela*. These buds are small, specialized leaves (fronds), which may be produced at almost any period of the growing season. They do not

have the large air spaces of the floating leaves. Their cells are laden with starch, the roots are rudimentary, and the stomata are closed. They sink to the bottom of the pond and may lie dormant there for several months, carrying the plant through the winter.

Pure cultures of *S. polyrhiza* were finally obtained by exposing the resting buds to a solution of sodium hypochlorite containing approximately 0.9 per cent by weight of available chlorine. (This product is marketed as 'Zonite'). This solution was diluted ten times with sterile distilled water in a sterile vessel. Resting buds were transferred with a sterile loop to this solution and shaken for five minutes. They were then transferred to a sterile nutrient solution similar to the one previously reported by the writer for the culture of *Spirodela* (Saeger, 1925). For five months the buds remained dormant. In January 1927 they germinated, floating on the surface and producing daughter fronds. After the plants had multiplied, some were removed and transferred to sterile nutrient broth. After a few days the broth was plated on nutrient agar. A single species of rod-shaped bacterium remained to contaminate the culture of *Spirodela*. Five months later this culture produced resting buds. These were then exposed to the sodium hypochlorite solution for 15 to 20 minutes, and transferred to a sterile dilute Knop's solution. Although the buds had been severely injured by this treatment, they germinated five days later and recovered. One of the resulting plants was transferred to nutrient broth. The broth remained clear. After a few days the broth was plated on sterile nutrient agar and incubated at room temperature for ten days. No growth developed either on the plants or on the culture medium. Later attempts to sterilize the resting buds by a single exposure to 10 per cent Zonite for 15 to 20 minutes were not successful. Sterility was checked by floating the plants on sterile glucose broth. No bacterial growth appeared, but the plants were in every case contaminated with a fungus.

During the summer of 1929 further attempts were made to sterilize the buds. Several disinfectants were tried, but without success. Exposure of each side of the buds for five minutes to radiations from a mercury vapor lamp (110 volt D. C., 5 ampere, at a distance of 30 cm.) injured the plants severely. They recovered and grew, but were not sterile, fungi remaining as contaminants.

The treatment with sodium hypochlorite seemed more promising. Sterile plants were again obtained by slightly modifying the method. Young resting buds that had been produced in cultures during the previous week were dropped into 95 per cent ethyl alcohol, where they remained for 15 seconds. They were then placed in a 10 per cent Zonite

solution for 15 to 20 minutes. After this treatment they were transferred aseptically to a sterile dilute Knop's solution. Erlenmeyer flasks with cotton stoppers over which tall beakers were inverted were used as culture vessels. All transfers were made in a steamed chamber in which only the necessary culture vessels were placed. The hands and arms of the operator were introduced through two small openings in the chamber. Three days after the treatment with the disinfectant the resting buds germinated. They had been subjected to illumination, in addition to daylight, from a 200 watt Mazda lamp over the period 5 P. M. to 10 P. M. After the plants had grown, one was removed aseptically and floated on glucose broth. Also a sample of the nutrient solution was transferred to glucose broth. No growth was detected in either case, after incubation for seven weeks at room temperature. It was decided that *Spirodela* was free from all contaminating organisms capable of growing in glucose broth or in the nutrient solution.

There was a tendency for the plants to become chlorotic in the sterile dilute Knop's solution. A small piece of iron wire introduced into the solution before sterilization served to maintain an iron equilibrium sufficient to prevent chlorosis. In such a solution the sterile plants will thrive for weeks without being transferred. Several preliminary experiments were carried out with the sterile *Spirodela*. One will be mentioned here to indicate the results when an organic extract of yeast is added to the sterile nutrient solution. One sterile two-leaved plant was placed into each of four flasks containing 100 cc. of the dilute Knop's solution, and into each of four similar flasks containing in addition the extract of 400 mg. autolyzed yeast per liter of solution. A similar extract had been used previously in non-sterile cultures of *Spirodela* (Saeger, 1925). After 22 days the mineral solutions contained 25 plants and the cultures with yeast extract contained 59 plants covering a much larger area. All plants were healthy in appearance. No dead leaves appeared in any of the cultures.

With reference to the contention of Mockeridge (1927) that green plants growing in mineral solutions may be supplied with 'auximones' through the activity of contaminating organisms, e.g., bacteria or algae, it may be said that pure cultures of *Spirodela* will grow successfully in mineral nutrient solutions without the presence of added organic matter. The successful culture of *Spirodela* in solutions of purified inorganic salts, without added organic matter, and in the absence of contaminating organisms, removes the last ground for maintaining Bottomley's contention (1920) that a minute amount of organic matter is *essential* for the nutrition of green plants (Lemnaceae)

It may be true, as indicated by the above experiment, that small

amounts of organic matter, when added to mineral nutrient solutions, may stimulate the growth of green plants in pure culture. With the development of a technique by which *Spirodela* may be freed from micro-organisms, a number of experiments dealing with the rôle of organic matter in the nutrition of green plants suggest themselves.

SUMMARY

1. A method is outlined for obtaining pure cultures of *Spirodela polyrhiza*.

2. *Spirodela* may be grown successfully, in pure culture, in a nutrient solution containing inorganic salts only.

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Coniothyrium terricola proves to be a species of Thielavia

CHESTER W. EMMONS

(WITH A TEXT FIGURE AND PLATE 4)

Among the cultures of fungi carried in stock in the Department of Dermatology of the College of Physicians and Surgeons of Columbia University is one originally labeled as *Coniothyrium terricola* Gilman and Abbott, No. 1722. This culture was obtained from the American Type Culture Collection, now located at the Bureau of Plant Industry, Washington, D. C. The fungus was originally isolated from the soil by Gilman and Abbott, and described as a new species in their work on 'A Summary of the Soil Fungi'[1] as follows:

> Colonies on bean agar broadly spreading, orbicular, pure white at first, later becoming smooth and steel gray. Pycnidia submerged in the mycelium, scattered, dark brown or black, mostly 100–200μ in diameter, globose to sub-globose, with small ostiolar papillae; spores very numerous, dark brown, elliptical, apiculate at both ends, 10–15μ long by 7–9μ broad; sporophores not observed.
>
> From soil: United States: Iowa, Louisiana.

Transfers from culture No. 1722 to plates containing one per cent corn meal agar fruited abundantly. It was observed that the fruiting structures were ascocarps instead of pycnidia, as they had been described by the authors of the species. Crushed mounts from cultures about one week old showed numerous pear-shaped asci, each containing eight spores. The fungus was shown to Dr. B. O. Dodge of the New York Botanical Garden, who recognized it as a species which he had isolated some years ago from decayed roots of strawberry at Chadbourn, North Carolina. The old cultures, derived originally from single ascospores, were turned over by him to the writer for study. They had been labeled 'Thielavia n.sp.'. These cultures, last transferred February 8, 1928, contained large numbers of ascocarps, now thoroughly dried out. The ascospores, however, germinated readily when transferred to fresh media, and ascocarps developed very quickly. The fruit bodies, asci, and ascospores appear to be identical with those developed in our cultures from No. 1722.

Thielavia basicola (B. & Br.) Zopf, which is the well-known species of the genus, is said to cause serious root rots of tobacco, sweet potato, violet, and many other plants. Dr. Florence McCormick[2] has proved that

[1] Gilman, J. C., and E. V. Abbott. A summary of the soil fungi. Iowa State College Jour. Sci. 1: 225–345. 1927.

[2] McCormick, F. A. Perithecia of *Thielavia basicola* Zopf in culture and the stim-

Thielaviopsis basicola (B. & Br.) Ferraris, characterized by its peculiar endospores and chlamydospores, is in no way genetically connected with *Thielavia basicola*, although the two species are often associated in rotting roots. Just which of the two fungi is the destructive agent was not proved. She found that pure cultures of *Thielavia* obtained from ascospores seldom produced perithecia. If, however, the cultures were contaminated with certain species of bacteria or fungi, then ascocarps were produced in abundance. The diagnostic features of ascocarps of *Thielavia*, described many times in the literature, are summarized by Gilbert[3] and again by Dr. McCormick. Perithecia of this form are about 70 to 100 microns in diameter, and the ascospores are 10 to 13×4.5 to 6.5 microns. The wall of the perithecium is very thin and transparent, much of the dark color being due to the color of the ascospores within.

As will be seen from the description and illustrations which follow, the fungus in culture No. 1722 from the Type Culture Collection belongs in the same genus with *Thielavia basicola*. Its behavior in culture and size of its ascospores are so different, however, as to warrant another specific name. *Coniothyrium terricola* Gilman and Abbott should, then, properly be referred to the genus *Thielavia* with the following revised description:

Thielavia terricola (Gilman & Abbott) comb. nov.

Colonies on corn meal agar broadly spreading, composed of white, cottony aerial hyphae and submerged hyphae, 1–6μ in diameter, branches constricted at base, homothallic; ascocarps arising from an ascogonial coil, sperical, without ostiole, 80–125μ in diameter in fresh cultures on corn meal agar, reaching up to 250μ in diameter in old cultures on malt agar, brownish to almost black at maturity, color largely due to masses of dark spores within; outer wall of perithecium composed of two or three layers of uninucleate rather thick-walled cells, somewhat carbonized; inner wall of perithecium composed of thin-walled, flattened cells; asci oval to pear-shaped, 16–19×25–35μ, deliquescing within the perithecium; ascospores broadly fusiform or elliptical, slightly apiculate at both ends, dark olivaceous to brown, 7–9×10–16μ, with a wall much thickened at the end opposite the germ pore. No asexual stage known.

Dried plate cultures derived from transfers from culture No. 1722 bearing ascocarps, and stained sections showing asci and spores, as well as dried cultures and stained sections of Dr. Dodge's material from North Carolina, have been deposited in the herbarium of the New York Botanical Garden.

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ulation of their production by extracts from other fungi. Conn. Agr. Exp. Sta. Bull. 269: 539–554. 1925.

[3] Gilbert, W. W. The root-rot of tobacco caused by *Thielavia basicola*. U. S. Dept. Agr. Bur. Plant Ind. Bull. 158: 1–55. 1909.

Dr. McCormick has pointed out that a species of *Thielavia*, apparently other than *T. basicola*, was carried in culture by Dr. Thaxter. Abbott[4] reports a species of fungus obtained from soil in Louisiana which he referred doubtfully to the genus *Thielavia*. Dr. N. E. Stevens who has for many years cultured various fungi from strawberry has sent the writer the following note regarding its occurrence in North Carolina:

This fungus was the most common fungus found on strawberry roots in a series of cultures made during 1928 and 1929 at Chadborun, N. C. Approximately 1,000 cultures were made each year. This fungus developed in 81 of the cultures in 1928; and in 91 of the cultures in 1929.

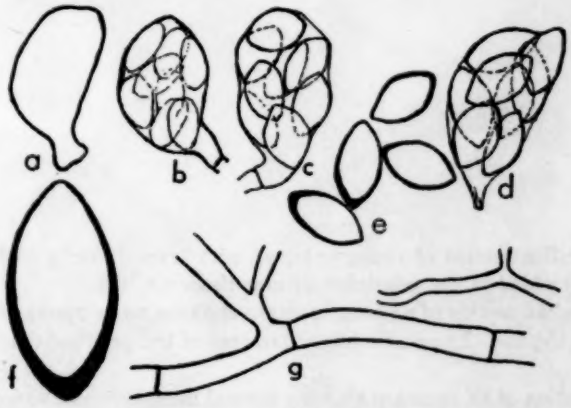

Fig. 7. Mycelium, asci, and spores of *Thielavia terricola*; *a-d*, spore development in the ascus (×500); *e*, mature spores (×500); *f*, mature spore, showing peculiar manner of wall thickening (×1315); *g*, mycelium (×500).

Whether *T. basicola* is a variable species, some races of which reproduce abundantly in pure culture as does our fungus, remains to be proved. The writer has made a number of monospore cultures from the Gilman and Abbott culture No. 1722, and from the material from North Carolina, derived, as noted above, from single ascospores. In all cases ascocarps were produced abundantly on corn meal agar within a week or ten days. Sections of ascocarps in various stages of development from the time the first uninucleate asci make their appearance, to the ripening of ascospores are shown in figures 1–4. Any crushed mount of sufficiently young material will show asci in all stages of maturity (figs. 5, 6.) Camera lucida drawings of asci and spores are shown in text figure 7. The development of the ascocarp from the ascogonium, and other cytological details are being worked out, and will be reported in a future paper.

[4] Abbott, E. V. A study of the microbiological activities in some Louisiana soils. Louisiana Agr. Exp. Sta. Bull. 194: 1–25. 1926.

Dr. B. O. Dodge, Consultant Mycologist at the Medical Center, has very kindly advised the writer regarding the identification of the fungus and in the preparation of this paper.

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COLLEGE OF PHYSICIANS AND SURGEONS
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Fig. 1. Median section of young ascocarp with several young asci in the uninucleate stage imbedded in the gelatinizing nurse tissue (×500).

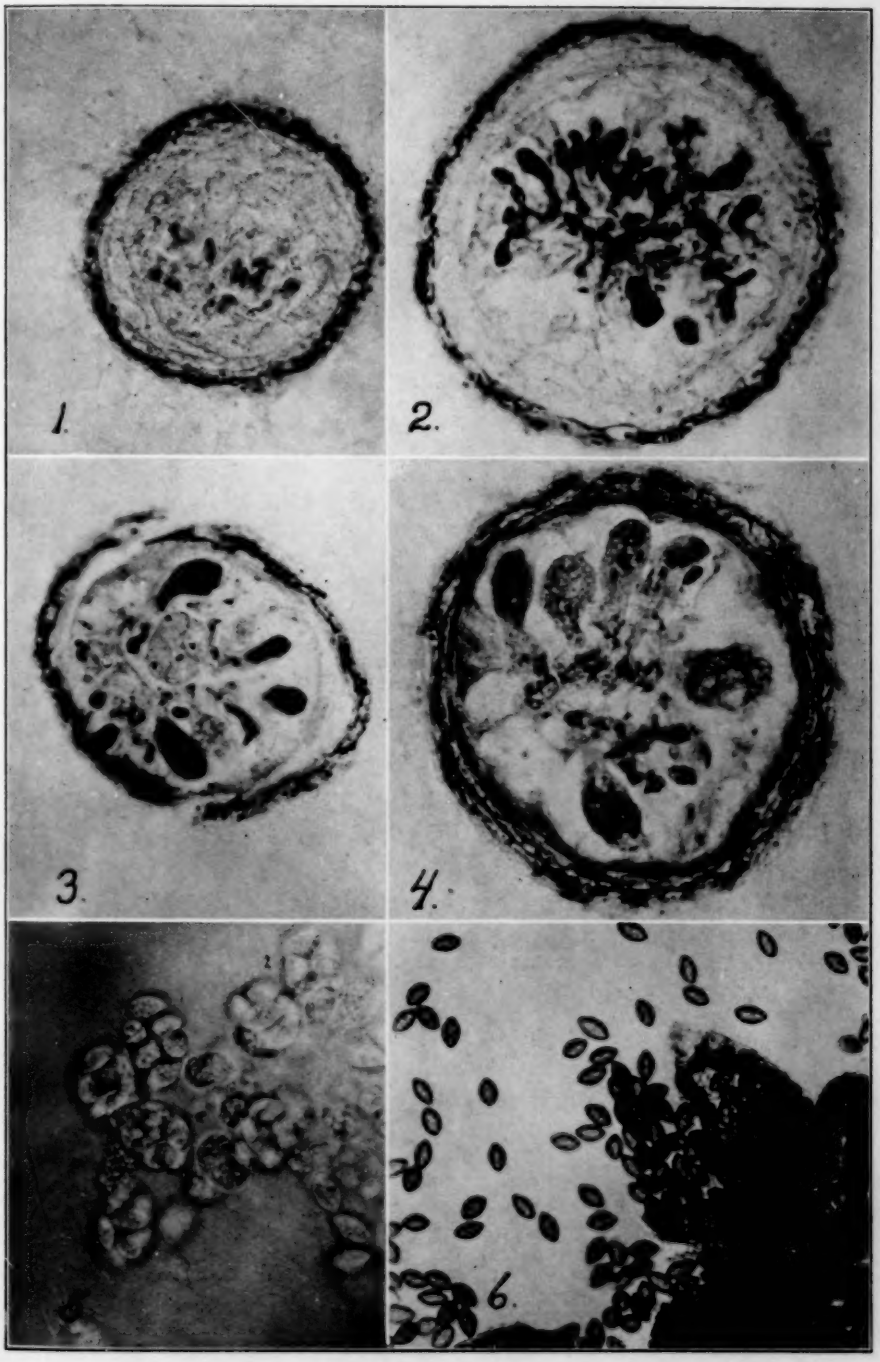
Fig. 2. Median section of a young ascocarp showing many young asci arising from the ascogenous hyphae. The uninucleate character of the perithecial cells can be seen (×500).

Fig. 3. Section of an ascocarp showing several immature asci and one nearly mature ascus cut in cross section so that four of the eight uninucleate spores are shown (×500).

Fig. 4. Median section of an ascocarp with three uninucleate asci, two in the binucleate condition, and one containing immature spores (×700).

Fig. 5. Crushed preparation of several asci and free spores (×500).

Fig 6. Crushed preparation of mature ascocarps. The asci have deliquesced and the spores were free within the ascocarps until liberated by the rupture of the perithecium (×300).



THIELAVIA TERRICOLA (GILMAN & ABBOTT) EMMONS

UNIV. OF MICH.

Toxic effects of iodine and nickel on buckwheat grown in solution cultures

MARJORIE COTTON

(WITH TWO TEXT FIGURES)

Recent investigations have shown that, in addition to the ten elements formerly supposed to be necessary for the growth and development of plants, a number of other elements, such as boron, manganese, zinc, silicon, aluminium, copper, etc., may be indispensable for normal growth of many kinds of plants (Brenchley, 1927; Mazé, 1914, 1919; Sommer and Lipman, 1926; Sommer, 1926, 1928; Stoklasa, 1922; McHargue, 1923, 1927). Little is known, however, regarding the physiological action of these elements. Mazé (1914) thinks that zinc is connected with the transportation of sulphates in corn plants. Mazé (1914) and McHargue (1923) suppose that manganese may play a rôle in the photosynthetic process. McHargue (1927) also suggests that chemical compounds of copper, manganese, zinc, nickel, and boron may act as plant vitamins.

In weak concentrations several of these elements serve as essential mineral nutrients, or they may act as stimulants, increasing the weight or improving the appearance of plants. In somewhat higher concentrations stimulative and toxic effects may be combined; for example, increased production of dry material may be accompanied by injury to the foliage. In still higher concentrations these elements may be extremely toxic.

It seems important to obtain as much information as possible concerning the physiological effects of all of the elements that are absorbed from the soil solution by plants. Further studies are needed of toxic effects, as well as of nutritive and stimulative effects. The present paper describes some experiments on the toxic effects of potassium iodide and nickel nitrate on buckwheat grown in solution cultures.

Iodine is widely distributed on the earth. It is found in most soils and rocks, peat and humus soils being especially rich in this element (Köhler, 1929). Plants may take up a certain amount of iodine from the soil, and they may also absorb it from the air (Stoklasa, 1926; Lunde, 1929). It has been known for a long time that sea water has a comparatively high concentration of iodine and that organisms living in the ocean contain more of this element than do fresh water organisms. Recent investigators estimate the iodine content of the ocean at about 0.02 p.p.m. (Lunde, 1929).

Iodine has been found to increase the activity of the nitrifying bacteria in the soil but to depress the ammonifying and denitrifying organisms

(Stoklasa, 1926, 1927). Clark (1899) reports that salts of iodine are much less harmful to fungi than the salts of heavy metals. Subjecting barley seeds infected with *Helminthosporium* to iodine vapors has been found to increase the disease caused by this fungus (Plaut, 1925).

Susuki and Aso (1902) reported that small amounts of iodine compounds increased the growth of various crop plants in pot cultures. Larger amounts caused the tips of the leaves to turn brown.

Mazé (1919) included iodine in the list of elements that he regarded as essential for securing complete development of corn plants in a nutrient solution. The results of his experiments on iodine, however, are not very conclusive, as he used a small number of plants in each culture—generally less than ten and in some cases only three—and the variability of the plants was high. Brenchley (1924) found that 0.1–0.0008 g. of sodium iodide per kg. of soil injured mustard and barley seedlings.

Stoklasa (1924, 1926, 1927) reports that xerophytes are easily injured by iodine, whereas halophytes and hydrophytes are actually benefited by this element. Sugar beets, which are descendents from halophytic plants, had a higher sugar content and produced more seeds when fertilized with potassium iodide. Stoklasa thinks that iodine is able to counteract the toxic action of the chlorine ion, and that it increases the rate of respiration and accelerates the oxidation of oxalic acid in plant cells.

It is well known that iodine is important for the functioning of the thyroid gland of man and that deficiency of this element in the nutrition may cause the formation of goiter. Recently several workers have tried to increase the iodine content of crop plants, so as to heighten their nutritive value. Scharrer and Strobel (1927) claim that the leaves of beets, spinach, etc., contain more iodine if the plants are fertilized with sodium iodate. Köhler (1929) came to a similar conclusion after applying potassium iodide to pot cultures of rye. Wrangel's (1927) experiments, however, gave no positive results.

Comparatively little work has been done on the effects of nickel on plant growth. Nickel is found in many soils, and Vernadsky (1922) demonstrated its presence in a large number of higher plants, mosses, and algae. Nickel seems to be be capable of acting as a strong poison. Jensen (1907) reported that young wheat plants growing in sand and in water cultures were greatly injured by low concentrations of nickel nitrate. Free and Trelease (1917) found that 5 p.p.m. of nickel, as nickel sulphate, produced clearly marked injury to young wheat seedlings growing in Shive's nutrient solution. Loew (1924) obtained no stimulation of plants from applications of small amounts of nickel sulphate to the soil. According to Richards (1897) and Ono (1900) nickel sulphate in low concentra-

tion stimulates *Aspergillus;* but in Niethammer's (1927) experiments this salt had no stimulative action on the fungus.

The present paper reports experiments upon the effects of potassium iodide and of nickel nitrate on the growth and development of buckwheat in solution cultures. The objects of this study were to determine the concentration of each of these salts which would inhibit growth, to determine the lowest concentration which would be toxic, and to determine whether these salts would be stimulative to the plants. Furthermore, a comparison was made between plants growing in good garden soil and plants growing in a full nutrient solution.

EXPERIMENT ON THE EFFECTS OF POTASSIUM IODIDE

The general methods used for growing the plants were similar to those described by Shive (1915), Livingston (1919), and Johnston (1921).

On December 26, 80 cc. of selected Japanese buckwheat seeds were soaked for four hours in distilled water obtained from a Barnstead still. They were then placed into germinating dishes between moist sheets of filter paper. When the roots had attained a length of 1–2 cm., the seedlings were arranged on paraffined bobbinet which had been fixed over enamelled germinating pans containing distilled water. Each pan stood in a similar somewhat larger pan which was filled with distilled water up to the rim of the inner pan. On January 5, after the seedlings had reached a height of about 6 cm., they were carefully transferred to the culture solutions. Flat corks had been prepared, similar to those used by Tottingham (1914) for wheat seedlings. The corks had been boiled three times in paraffin. Into each cork four seedlings were inserted and held in position by cotton plugs. The corks bearing the seedlings were then placed in two-quart Mason jars that had been thoroughly cleaned and that contained the nutrient solutions.

Each culture consisted of four Mason jars, containing a total of sixteen plants. Jackets of card-board around the jars prevented light from striking the roots. Dowels about 70 cm. high were inserted into the corks, and as the plants grew they were tied to the dowels. The jars were placed on two adjacent rotating tables in the greenhouse. Two jars of each series were on each table, and every fortnight the plants were moved from one table to the other. Four Mazda-C electric lamps, having a total value of 1600 watts, were suspended about 150 cm. above each table, in order to improve the light conditions. They were kept lighted daily from 8 a.m. to 5 p.m., except at hours when the sun was shining fully onto the plants. The average daily maximum temperature was 26.2° C. and the corresponding minimum was 16.9° C. The evaporating power of the air—measured

by weekly readings of corrected Livingston white spherical atmometers—showed a daily mean of 13 cc. (Livingston, 1915). Radiation was measured by the difference in evaporation from white and from blackened atmometers; the daily mean difference was 1.9 cc.

Culture 1 was supplied with a standard solution containing 0.006 M KH_2PO_4, 0.002 M $Ca(NO_3)_2$, 0.002 M $MgSO_4$, and 0.00001 M $FeSO_4$. Culture 2 received the standard solution; in addition to the salts of culture 1, it contained ten other salts which have been claimed to be beneficial to plant growth, in very dilute concentrations. The concentrations of these salts were as follows:

0.000010 M $MnSO_4$ or 0.55 p.p.m. Mn
0.000004 M $ZnSO_4$ or 0.26 p.p.m. Zn
0.000010 M H_3BO_3 or 0.11 p.p.m. B
0.000004 M $Al_2(SO_4)_3$ or 0.22 p.p.m. Al
0.000010 M NaCl or 0.58 p.p.m. NaCl
0.000002 M $Co(NO_3)_2$ or 0.12 p.p.m. Co
0.000002 M $Ni(NO_3)_2$ or 0.12 p.p.m. Ni
0.000006 M $LiNO_3$ or 0.04 p.p.m. Li
0.000002 M $CuSO_4$ or 0.13 p.p.m. Cu
0.000003 M KF or 0.06 p.p.m. F

The pH value of every solution was about 4.6. The osmotic concentration was about 0.5 atmosphere. The effect of adding various amounts of potassium iodide to solution 2 was tested (table 1).

TABLE 1

Top yields of buckwheat plants grown for 70 days in nutrient solutions containing potassium iodide[a]

CULTURE NUMBER	CONCENTRATION OF KI	P.P.M. OF I	MEAN TOP YIELD	RELATIVE YIELD
	Gram-molecule per liter		*Grams*	
1	0.000000	0.	1.435±0.090	84.2
2	0.000000	0.	1.701±0.107	100.0
3	0.000001	0.13	1.541±0.098	90.7
4	0.000003	0.38	1.184±0.085	69.6
5	0.000010	1.27	1.195±0.084	70.3
6	0.000032	4.06	0.256±0.075	15.0
7	0.000100	12.7	0.082±0.020	4.8
8	0.000316	40.1	0.029±0.003	1.7
9	0.001000	126.9	0.017±0.001	1.0

[a]The data for cultures 4, 8, and 9 are for 14 plants, those for cultures 6 and 7 are for 15 plants, and those for the other cultures are for 16 plants.

Solutions were made up for two jars of one culture at a time, and renewals were made weekly. Observations were recorded once or twice a week. After growing for 70 days in the culture solutions, the plants were

harvested individually, the tops being separated from the roots. When the tops had become air-dry, they were kept in an oven at 100° C. for 21 hours, and their dry weight was then determined.

Potassium iodide appeared to be a very strong poison for the young buckwheat plants. A number of the plants of culture 9 (0.001000 M KI) and culture 8 (0.000316 M KI) were killed within the first week. The remaining plants made very poor growth, and by the end of the third week all of the plants of culture 9 and all but one plant of culture 8 were dead. This surviving plant produced one small cluster of flowers. After five weeks the plants of these cultures were harvested.

By this time most plants of culture 7 (0.000100 M KI) and some of culture 6 (0.000032 M KI) had also been killed. The remaining ones were flowering. All of these plants and nearly all the plants of culture 5 (0.000010 M KI) showed signs of poisoning.

The symptom of iodine injury was the development of characteristic spots, which generally appeared first as slightly sunken areas, often near the margin of the leaf. The spots later turned pale brown and were bordered by a darker brown circle. The discolored areas enlarged and finally coalesced, so that a large part of the leaf dried up. Then the petiole, which had remained turgid all the while, turned brown at the base. At this stage the leaf usually dropped off, but in some instances the whole petiole dried up while remaining attached to the stem. In severe cases of poisoning the apex of the stem withered and dried.

Two sets of culture 7 were taken down after six weeks and the others were harvested after the seventh and ninth weeks.

During the sixth and seventh weeks of the experiment the first sunken brown spots appeared on plants growing in culture 4 (0.000003 M KI), and after eight weeks iodine spots appeared on three plants of culture 3 (0.000001 M KI—the weakest solution of iodine tested).

On March 15, when the plants were harvested, six plants of culture 3 showed distinct traces of iodine injury. On five more plants small brown spots were detected, which may also have been caused by iodine. Otherwise, however, the plants were strong and healthy. All the plants of cultures 4, 5, and 6 were more or less heavily spotted. The plants of culture 2 looked slightly more vigorous than those of culture 1. Ripe seeds were collected from cultures 1, 2, 3, 4, 5, and 6.

The data for the dry weights of the tops are recorded in table 1 and plotted in figures 1 and 2. In these graphs the ordinates represent relative dry weights expressed as percentages of the dry weight for culture 2. The abscissas of figure 1 represent molecular concentrations of KI and those of figure 2 parts per million (p.p.m.) of iodine. Abscissas of both

figures are plotted on a logarithmic scale, except for the zero concentration.

It will be noticed that potassium iodide caused a gradual depression of growth as the poison was increased up to a concentration of 0.00001 M (1.27 p.p.m. iodine). Then the curve drops rapidly, indicating the highly injurious effect of the poison in greater concentrations. In concentrations

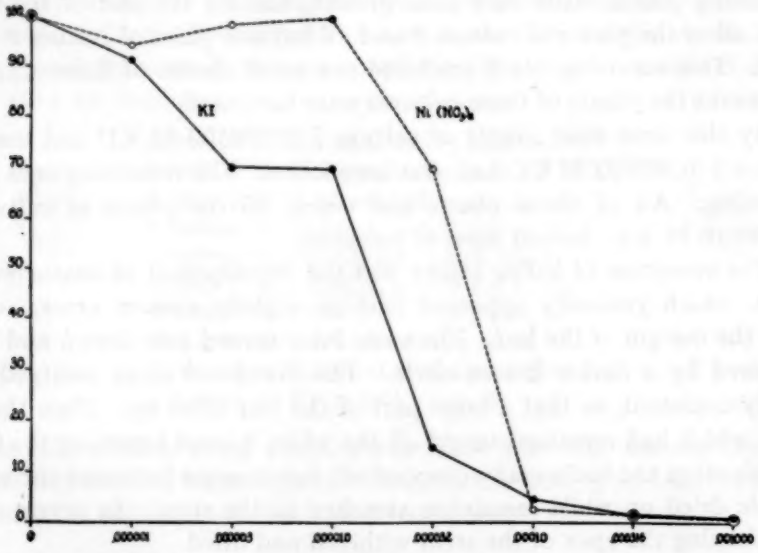


Fig. 1. Growth of buckwheat in nutrient solutions containing potassium iodide and nickel nitrate. Ordinates represent relative dry yield of tops. Abscissas represent concentration in gram molecules per liter (logarithmic scale, except the zero concentration).

equalling 0.000316 M (40.1 p.p.m.) and 0.001 M (126.9 p.p.m.) practically no growth occurred.

The data of table 1 seem to indicate that plants of culture 1, grown only in the presence of the three chief nutrient salts and a trace of iron, are somewhat depressed in growth as compared with those of culture 2, grown with an additional amount of Mn, Zn, Al, B, etc. Statistical calculations show that this difference may be significant. The difference in mean top yields between plants of cultures 2 and 1 is 0.266 g. This difference amounts to 1.9 times its probable error ($0.266 \div 0.14 = 1.9$). The odds against such difference occurring under uniform conditions, according to Wood (1911), are only 4 to 1. Thus, we have no high degree of assurance that this difference is significant.

The value for the mean dry weight of the plants of culture 4 may be questioned. It is based upon only fourteen specimens; one plant was

lost, and another made exceptionally poor growth, owing to unknown conditions. A repetition of this experiment showed that the dry weight of plants receiving the same concentration of potassium iodide as those of culture 4 (but with nickel nitrate in a concentration of only 0.000001 M) was no lower than that of the control plants, although nearly all the plants showed signs of injury.

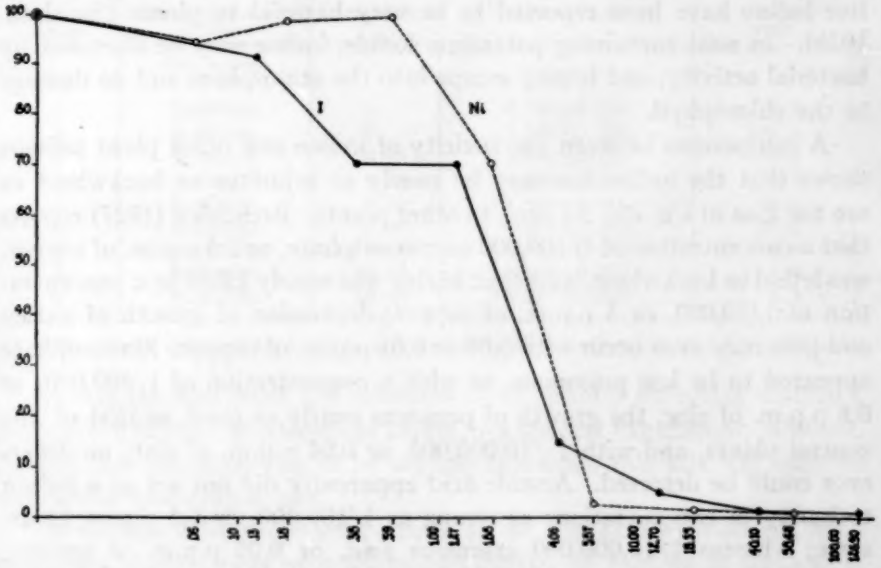


Fig. 2. Growth of buckwheat in nutrient solutions containing potassium iodide and nickel nitrate. Ordinates represent relative dry yield of tops. Abscissas represent concentration in parts per million of I and Ni (logarithmic scale, except the zero concentration).

The difference of weights between cultures 2 and 5 is real ($0.506 \div 0.14 = 3.6$), the odds against such difference occurring under uniform conditions being larger than 30 to 1 and smaller than 140 to 1. Stronger concentrations of potassium iodide depressed growth greatly.

It was interesting to observe that individual buckwheat plants showed different degrees of resistance to the poison. One plant in solution 8 produced flowers after all the other fifteen plants in the same solution had been killed. Some plants of culture 5 had developed iodine spots at the end of the third week, whereas one plant did not start to show signs of poisoning until after eight weeks. Also, only half the plants of culture 3 became spotted; the rest appeared to be perfectly healthy when harvested.

Brown spots due to iodine poisoning have been reported by Mazé (1919) and Susuki and Aso (1902).

A very interesting result obtained from the experiment was that iodine appeared to be an extremely strong poison to buckwheat, as 0.13 p.p.m. iodine, or a concentration of 0.000001 M potassium iodide, in the nutrient solution injured the foliage. The poisonous action may be due to the fact that a relatively large amount of free iodine may be formed in the comparatively acid nutrient solution (pH 4.6). Large amounts of free iodine have been reported to be very harmful to plants (Stoklasa, 1926). In soils containing potassium iodide, iodine may be liberated by bacterial activity, and it may escape into the atmosphere and do damage to the chlorophyll.

A comparison between the toxicity of iodine and other plant poisons shows that the iodine ion may be nearly as injurious to buckwheat as are the ions of Cu, Zn, As, etc., to other plants. Brenchley (1927) reports that a concentration of 1/100,000 copper sulphate, or 2.5 p.p.m. of copper, was lethal to buckwheat, and that barley was nearly killed in a concentration of 1/50,000, or 5 p.p.m. of copper; depression of growth of barley and peas may even occur with 0.05 or 0.01 p.p.m. of copper. Zinc sulphate appeared to be less poisonous, as with a concentration of 1/500,000, or 0.8 p.p.m. of zinc, the growth of peas was nearly as good as that of the control plants, and with 1 /10,000,000, or 0.04 p.p.m. of zinc, no difference could be detected. Arsenic acid apparently did not act as a poison to barley in concentrations as strong as 1/100,000, or 5.3 p.p.m. of arsenic; whereas 1/10,000,000 arsenious acid, or 0.06 p.p.m. of arsenic, depressed growth. No growth occurred with 1/10,000 arsenious acid, or 60 p.p.m. of arsenic. Peas were stimulated at a concentration of 1/100,000 boric acid, or 1.8 p.p.m. of boron; whereas 1/2,500,000 boric acid, or about 0.07 p.p.m. of boron, was poisonous to the leaves of barley.

EXPERIMENT ON THE EFFECTS OF NICKEL NITRATE AND ON A COMPARISON OF GROWTH IN SOLUTION AND SOIL CULTURES

The general methods for growing the plants were the same as those described for the first experiment. Germination of the seeds was started on February 15, and on February 25 the seedlings were transferred to the nutrient solutions. The temperature conditions were similar to those during the previous experiment; the average daily range was from 16.8° C. to 26.5°C. The evaporating power of the air was slightly lower than before. Corrected Livingston atmometers showed a daily mean of 11.2 cc. The daily mean difference of evaporation from white and blackened atmometers, indicating radiation, was 1.8 cc.

The nutrient solution of culture 1 was the same as that of culture 1 of the first experiment. Culture 2 differed from the corresponding culture

of the former experiment only by the absence of nickel nitrate. The effects of adding various amounts of nickel nitrate to the solution of culture 2 were tested (table 2).

TABLE 2

Top yields of buckwheat plants grown for 70 days in nutrient solutions containing nickel nitrate[a]

CULTURE NUMBER	CONCENTRATION OF $Ni(NO_3)_2$	P.P.M. OF Ni	MEAN TOP YIELD	RELATIVE YIELD
	Gram-molecule per liter		*Grams*	
1	0.000000	0.	1.106±0.033	72.2
2	0.000000	0.	1.531±0.100	100.0
3	0.000001	0.06	1.436±0.121	94.0
4	0.000003	0.18	1.509±0.074	98.5
5	0.000010	0.59	1.525±0.066	99.6
6	0.000032	1.88	1.076±0.080	70.3
7	0.000100	5.87	0.043±0.003	2.8
8	0.000316	18.55	0.022±0.001	1.4
9	0.001000	58.68	0.017±0.000	1.1

[a] The data for culture 3 are for 15 plants, while those for the other cultures are for 16 plants.

During the first week the solutions of all cultures excepting culture 1 contained 0.000001 M potassium iodide. As the first experiment, however, showed this concentration to be slightly injurious, this salt was omitted during the following weeks.

On February 16, three soil cultures (I, II, and III) were set up, each composed of eight pots with thirty-two plants. A number of seeds were planted in 4-inch clay pots filled with good garden soil. After one week four seedlings of equal height were selected, and the others were removed. Culture I was arranged on the rotating tables together with the plants growing in the solutions. Culture II was placed around the tables; the plants of this culture did not receive quite so much light as did the plants of culture I. Culture III was placed in another part of the greenhouse in ordinary daylight.

All the plants were harvested after 70 days.

During the first week of the experiment, nearly all the plants of culture 9 (0.001000 M $Ni(NO_3)_2$) died; some of them had died within three days. The stems lost their rigidity, and the seedlings collapsed. The cotyledons remained green for a while and then dried up. In the course of the first two weeks the stems of most plants of culture 8 (0.000316 M Ni $(NO_3)_2$) also wilted, and the cotyledons became flaccid and developed brown spots. Some of these plants died without further development, while others pushed out a pale new leaf which soon became covered with brown spots, chiefly at the tip. One plant produced a small flower bud

that never opened. The plants of culture 9 were harvested after the second week, those of culture 8 after the fifth and sixth weeks.

The plants of culture 7 (0.000100 M $Ni(NO_3)_2$) did not collapse, but the cotyledons became heavily spotted. The growing points turned a reddish brown, the new leaves were yellow, and nearly all plants of this culture were dead by the end of the fourth week. The few that survived made a little growth, and pushed out pale, unhealthy looking new shoots and small flower buds. Brown lesions appeared on their stems, and the roots remained small.

The plants of culture 6 (0.000032 M $Ni(NO_3)_2$) were also stunted. The leaves became chlorotic. The regions near the veins remained dark green, whereas the areas between them became pale. As time went on, minute dry spots of a light brown color appeared on nearly all the leaves. The spots were much paler and smaller than those caused by iodine poisoning.

Up to the third week the plants growing in soil looked more vigorous than those growing in the solutions. Then, for a period of several weeks, there was no apparent difference between the two sets, but later the plants growing in the solutions looked stronger than the ones growing in soil. The superiority of the plants in the solutions was perhaps due to the fact that these plants received a constant supply of minerals, whereas the plants in the soil cultures may have suffered from a deficiency of minerals as they grew larger.

TABLE 3

Top yields of buckwheat plants grown for 70 days in nutrient solutions and in soil

CULTURE NUMBER	NUMBER OF PLANTS	CULTURE MEDIUM	TOP MEAN YIELD	RELATIVE YIELD
			Grams	
1	16	Solution	1.106±0.033	72.2
2	16	Solution	1.531±0.100	100.0
I	32	Soil	1.050±0.049	68.6
II	30	Soil	1.018±0.058	66.6
III	30	Soil	1.071±0.051	70.0

After four weeks most plants of cultures 1, 2, 3, 4, 5, and 6 were flowering. Twenty-one plants of culture II and all but three plants of culture I, growing in soil, were also in bloom. But only sixteen of the plants of culture III, growing without additional light, had produced flowers.

At the end of the experiment, after ten weeks, seven plants of culture 5 (0.000010 M $Ni(NO_3)_2$) were slightly chlorotic. The plants of cultures 1, 2, 3, and 4 were all strong and healthy, and their general appearance was better than that of the plants growing in soil (cultures I, II, III).

In culture I five plants had died, and four plants in culture II and the

same number in culture III had wilted owing to unknown conditions. Most of the plants in culture III had produced only one or two small clusters of flowers, and one plant did not flower at all.

The data for the dry weights are recorded in tables 2 and 3 and are plotted in figures 1 and 2. The highest yield was obtained from the plants of culture 2. Statistical calculations show that the difference between cultures 1 and 2 is really significant. The difference is greater than in the first experiment and amounts to 4 times its probable error ($0.425 \div 0.106 = 4.0$). The odds against such a difference occurring under uniform conditions (according to Wood, 1911) are 140 to 1.

Concentrations of nickel nitrate ranging from 0.000001 M to 0.00001 M (0.06 to 0.59 p.p.m. nickel) did not affect the yield of the plants, although the latter concentration produced slight chlorosis in some cases. A concentration of 0.000032 M (1.88 p.p.m.) caused a distinct depression of growth. A remarkable difference in weight appeared between plants receiving 0.0001 M and 0.000032 M nickel nitrate: the mean dry weight of the plants growing in the stronger solution was only about one twenty-fifth as large as that of the plants growing in the weaker solution.

As regards the plants of the soil cultures, no significant differences in weight are shown by the data of table 3. The only difference between these cultures was that the plants grown in poor light (*i.e.*, ordinary greenhouse illumination) produced fewer flowers. Higher yields were obtained from plants grown in the full nutrient solution than from those grown in soil. This difference was 4.3 times its probable error ($0.481 \div 0.112 = 4.3$), and the odds against such a difference occurring under uniform conditions lie between 140 to 1 and 1000 to 1. The plants of culture 1, grown in a solution containing only the three main nutrient salts and iron had about the same dry weight as those grown in the soil. Hoagland (1919) reports experiments in which plants grown in water and in sand cultures gave as high yields as plants grown in soil under the same environmental conditions.

Chlorosis is, of course, not a specific symptom of nickel poisoning. Manganese, zinc, chromium, and selenium ions have also been reported to cause chlorosis (Johnson, 1924; Gračanin, 1928; König, 1910; Turina, 1922).

Nickel nitrate seemed to be less injurious to buckwheat than was potassium iodide. Signs of poisoning without depression of growth appeared at 0.00001 M nickel nitrate, or 0.59 p.p.m. of nickel. Weaker solutions had no apparent effect. But potassium iodide in concentrations as low as 0.000003 M and 0.000001 M (0.38 and 0.13 p.p.m. of iodine) was definitely harmful to the plants.

SUMMARY

A study was made of the toxic effects of potassium iodide and nickel nitrate on buckwheat plants growing in solution cultures. The plants were grown in a solution containing KH_2PO_4, $Ca(NO_3)_2$, $MgSO_4$, and $FeSO_4$, and in a second solution containing the following additional salts in low concentrations: $MnSO_4$, $ZnSO_4$, H_3BO_3, $Al_2(SO_4)_3$, NaCl,$Co(NO_3)_2$, $CuSO_4$, $LiNO_3$, KF. In the first of the two experiments here reported the plants also received a low concentration of $Ni(NO_3)_2$. The poisonous effects of potassium iodide and nickel nitrate, when added in various strengths to the second solution, were studied.

Potassium iodide was extremely injurious to the buckwheat plants. Concentrations equalling 40.1 p.p.m. and 126.9 of iodine killed nearly all of the plants within three weeks. Marked depression of growth occurred in concentrations ranging from 1.27 to 12.7 p.p.m. Although weaker concentrations did not reduce growth, they had a toxic effect on the leaves. In all tested concentrations iodine caused pale brown spots surrounded by a darker margin to appear on the leaves. Iodine had no stimulative action.

Nickel appeared to be less harmful than iodine. Concentrations of from 5.87 to 58.68 p.p.m. of nickel were very toxic. In the stronger solutions the stems and the leaves lost their turgidity and the young plants died within two weeks. In a concentration corresponding to 5.87 p.p.m. of nickel most of the plants also died. The surviving plants were stunted in their growth; new leaves that developed were yellow and covered with minute brown spots, and brown lesions appeared on the stems. A concentration of 1.88 p.p.m. of nickel caused spotting and chlorosis of leaves and depression of growth. In some cases 0.59 p.p.m. of nickel caused chlorosis without affecting growth. Weaker concentrations were neither toxic nor stimulative.

Plants supplied with a full nutrient solution containing minute quantities of $MnSO_4$, $ZnSO_4$, H_3BO_3, $Al(SO_4)_3$, NaCl, $Co(NO_3)_2$, $CuSO_4$, $LiNO_3$, and KF made decidedly better growth than plants grown in a solution containing only the three main nutrient salts and iron.

A markedly higher yield was obtained from plants grown in a full nutrient solution than from those grown in good garden soil, under the same environmental conditions. Equal growth occurred in the soil and in a solution containing only the three main salts and iron.

Additional light caused plants in soil cultures to produce more flowers, but did not increase the yield of dry material.

In conclusion the writer acknowledges her indebtedness to Dr. Sam F. Trelease for advice and many helpful suggestions.

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INDEX TO AMERICAN BOTANICAL LITERATURE
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